SR 308 MP 2.16 Unnamed Tributary to Liberty Bay (991000): Preliminary Hydraulic Design Report

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ROLES AND RESPONSIBILITIES FOR THIS PRELIMINARY HYDRAULIC DESIGN REPORT

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) Report are defined as follows for the Olympic Region General Engineering Consultant (GEC):

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this PHD Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form (TVF). The QC methods are defined in the Olympic Region GEC Quality Management Plan (QMP) Section 5.3 and the QMP Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead PE or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

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Contents

Figures

Tables

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 308 crossing of Unnamed Tributary (UNT) to Liberty Bay at milepost (MP) 2.16 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier (ID) 991000) and has an estimated 5,170 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the confined bridge design methodology because of the confined nature of the channel and the meander belt width of 20 feet. SR 308 is an essential access road to rural communities in Lewis County and cannot be abandoned.

The crossing is located in Kitsap County, 1.25 miles west of Keyport, Washington, in WRIA 15. The highway runs in an east-west direction at this location 0.5 mile upstream from the confluence with Liberty Bay (see Figure 1 for the vicinity map). This UNT to Liberty Bay generally flows south to north beginning approximately 2.0 miles upstream of the SR 308 crossing.

The proposed project will replace the existing 114-foot-long, 30-inch-diameter concrete culvert with a structure designed to accommodate a minimum hydraulic width of 20 feet. The proposed structure is designed to meet the requirements of the federal injunction using the confined bridge design criteria as described in the 2013 WDFW Water Crossing Design Guidelines (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT Hydraulics Manual (WSDOT 2022a).

Structure type is not being recommended by Headquarters Hydraulics and will be determined by others at future design phases. No design deviations have been proposed for this project.

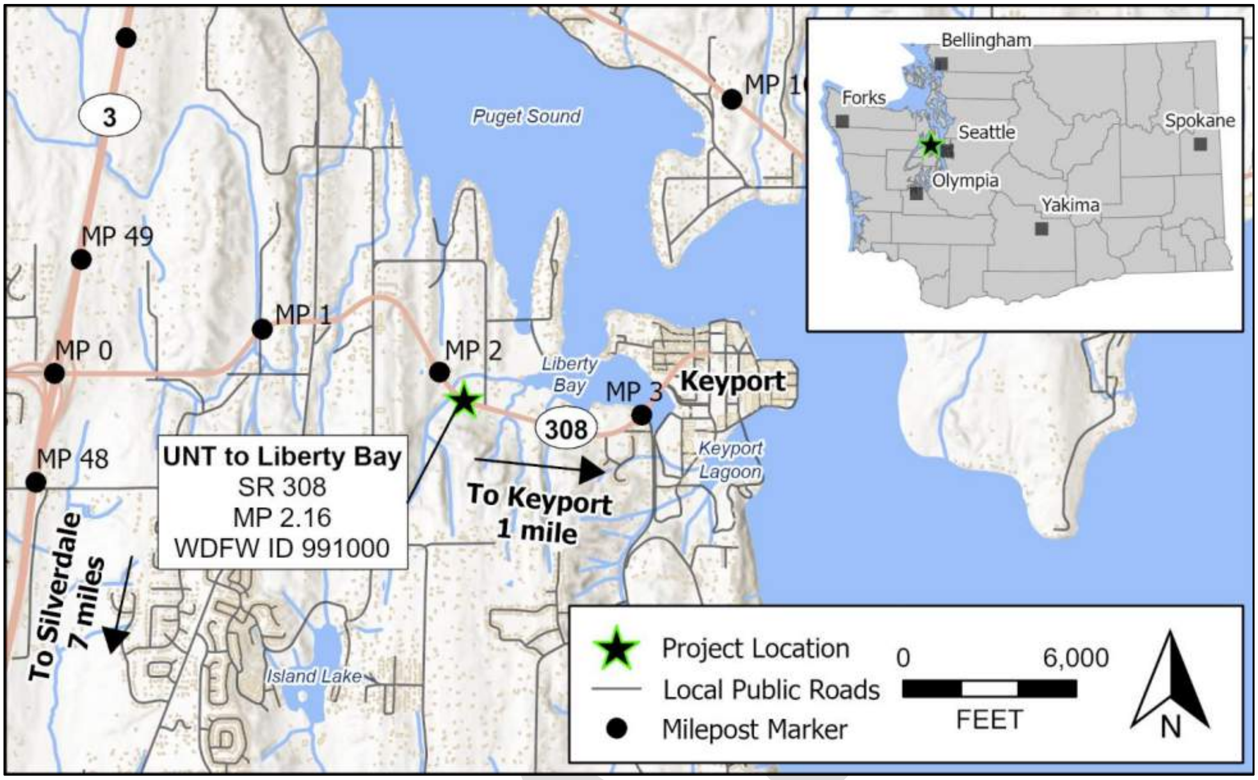

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed through a combination of a site visit and desktop research using resources such as those provided by the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, as well as past records such as inspection and maintenance reports.

2.1 Site Description

The culvert under SR 308 at MP 2.16 (WDFW ID 991000) for the UNT to Liberty Bay is listed as a barrier due to excessive slope (WDFW 2004a). The culvert drops 2.18 feet over the 114-foot length, resulting in a slope of 1.9 percent. In addition, there is a 1.5-foot drop on the downstream end of the culvert. The slope causes high velocities within the culvert, and with no flow obstructions to provide resting areas within the culvert, neither adult nor juvenile salmonids are able to migrate upstream. The 1.5-foot drop on the downstream end of the culvert is also a barrier, because salmonids are unable to jump the vertical gap between the pool and culvert outlet. As a result of these two barriers, salmonids cannot pass through this structure.

This crossing is not listed as a Chronic Environment Deficiency (CED) or failing structure (WSDOT 2020). Maintenance records were requested from the WSDOT Project Engineer's Office (PEO) in January 2022, but no maintenance records for the culvert were available. However, as-builts and roadway overlay maintenance records were provided. There does not appear to be any issues with sediment deposition or flooding in the vicinity of the existing culvert. Distinct high-water marks were not evident during the site visit. The removal of this fish passage barrier will provide an estimated 5,170 LF of potential habitat gain (WDFW 2004a).

2.2 Watershed and Land Cover

This UNT of Liberty Bay drains approximately 0.31 square mile of a relatively undeveloped, north-facing hillside located within the Kitsap Peninsula (see Figure 2). The watershed contributing to the existing culvert was delineated using Geographic Information Systems (GIS) software and topographical data obtained from light detection and ranging (LiDAR) survey data. The resulting basin was cross-referenced with aerial imagery (NAIP 2015) to deduce whether development at the upstream end of the watershed may have stormwater infrastructure that could have a large impact on this basin's hydrology; this does not appear to be the case. There is a small confluence approximately 1,000 feet upstream of the project location. The watersheds for each of the tributaries are included in the watershed for this project.

The minimum and maximum elevations of the basin with respect to the North American Vertical Datum of 1988 (NAVD88) are approximately 50 feet and 380 feet, respectively. The annual average precipitation within the basin is 42.5 inches (PRISM Climate Group 2021).

According to The National Land Cover Dataset (NLCD, 2019) the basin is approximately 64 percent undeveloped and 36 percent lightly developed. The undeveloped areas are primarily forested, and the developed areas are primarily low intensity development and developed open space (see Figure 3). Google Earth aerial imagery from 2020 reveals that the development at the upstream, southern end of the watershed is primarily residential (Google 2020). See Table 1 for a summary of the land cover classes within the basin.

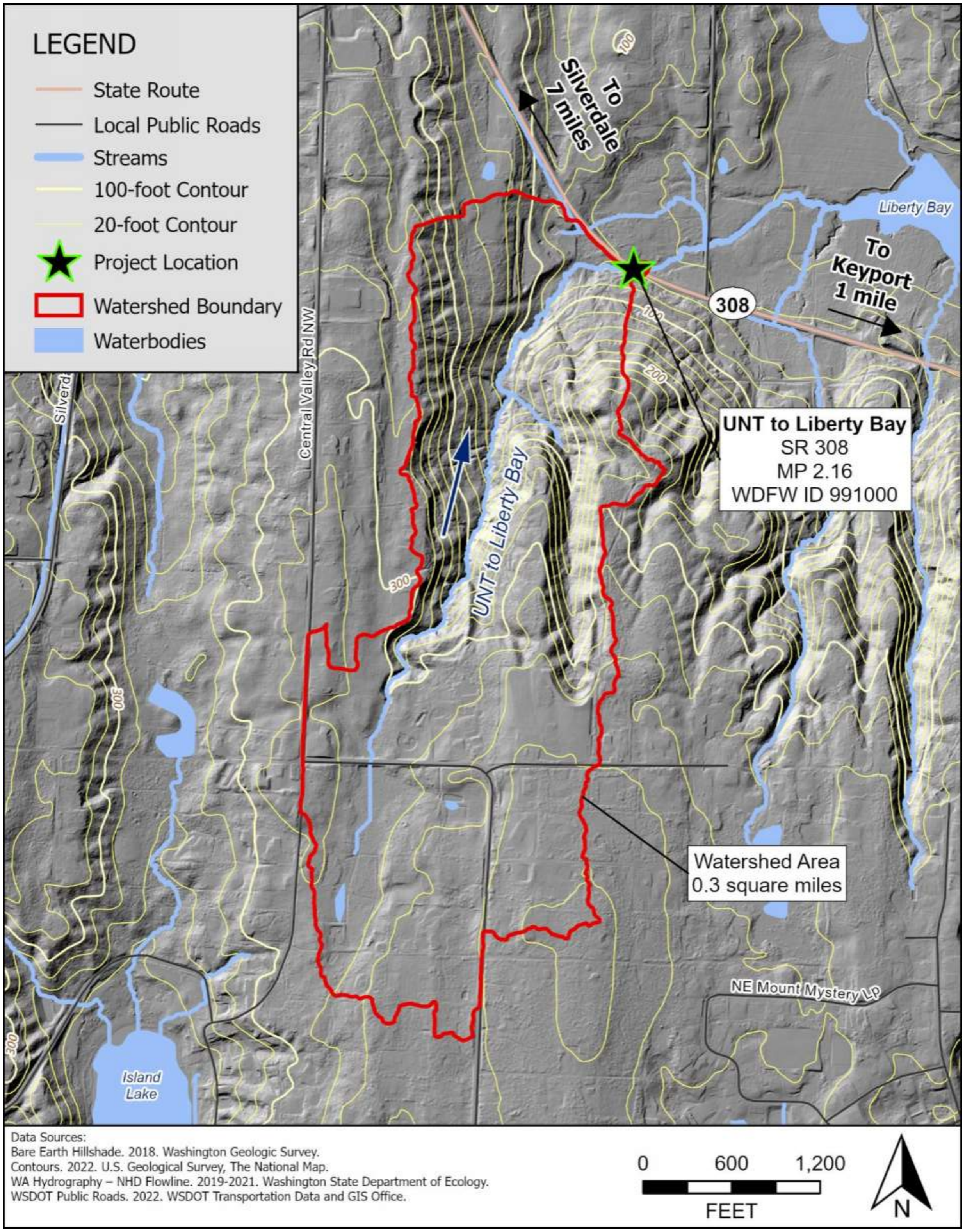

Figure 2: Watershed map

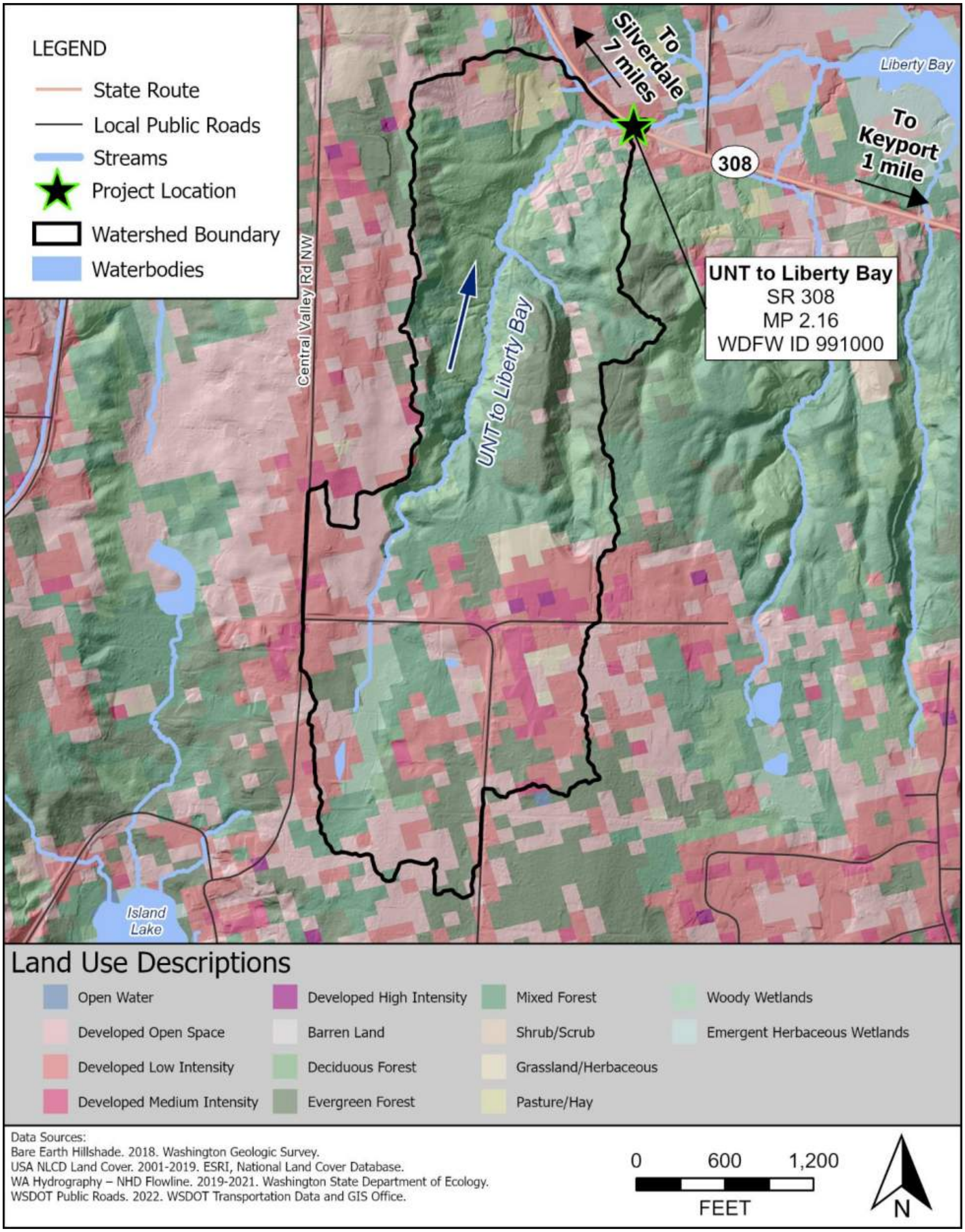

Figure 3: Land cover map (NLCD 2019)

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Developed, Open Space	16%
Developed, Low Intensity	16%
Developed, Medium Intensity	4%
Developed, High Intensity	0.2%
Deciduous Forest	18%
Evergreen Forest	16%
Mixed Forest	24%
Shrub/Scrub	0.1%
Grassland/Herbacious	2%
Pasture/Hay	2%
Woody Wetlands	2%

2.3 Geology and Soils

The existing SR 308 crossing is located on the east side of the Kitsap Peninsula within the Puget Lowlands. The Puget Lowlands topography is shaped by both glacial and non-glacial processes. Continental glaciers eroded and deposited material with each advance and retreat from the north, leaving behind a glaciated surface of parallel fluted ridges with pockmarked irregular depressions (Haugerud 2009) (see Figure 4). The last continental ice sheet retreated from the Puget Lowlands approximated 16,420 calculated years before present (Porter and Swanson 1998). Pleistocene continental glacial drift (Qpos) is the primary geologic unit deposited in the project area, and there is some Pleistocene continental glacial till (Qgt) in the northwestern corner of the watershed (see Figure 5). Continental glacial drift includes sand with some pebbles and silt. Continental glacial till is an unsorted deposit of sand, gravel, cobbles, and some boulders suspended in a fine matrix of silt and clay and typically has low permeability.

The existing SR 308 crossing is located within a valley of non-glacial deposits of Quaternary bog and lake deposits (Qp), and hillslope mass wasting deposits of colluvium (Qmw). Colluvium consists of unsorted glacial and non-glacial material transported by slope failures and contains the addition of local organic material. From the south, the upper reaches of the stream flow through Quaternary bog and lake deposits (Qp) of peat and organic-rich sediments, and then the stream proceeds to cut through a steep valley of colluvium consisting of Quaternary hillslope mass wasting deposits (Qmw) (see Figure 5).

The existing SR 308 crossing is located within a reach where the stream transitions from a steeper and confined reach that has downcut into the hillslope to a reach within an alluvial fan, as identified by Haugerud (Haugerud 2009) (see Figure 4). The alluvial fan is composed primarily of Pleistocene age deposits (DNR Geology Portal 2022) that were depositing during the glacial melt water period, when the sediment transport was much greater due to higher flows from the retreating glaciers. See Sections 2.7.5 and 7.1 for discussion of lateral migration risks for this project. See Section 4.2.2 for discussion on how lateral migration risks were accounted for when sizing the minimum hydraulic opening.

Landslides within the valley and urbanization of the watershed have increased runoff and sediment supply to the streams. The valley walls are steep and have mapped landslides along the main path of the stream and along the tributary (DNR Geology Portal 2022; Haugerud 2009). The stream erodes the toe of hillslopes, destabilizing the material, which causes slope failures and supplies the stream with sediment and vegetative debris. The southern and northern portions of the watershed are lightly developed with residential neighborhoods (see Figure 3). This developed landscape contributes to increased rates of runoff because of the associated impervious surfaces. Developed land also has less vegetation coverage, thereby reducing the natural absorption of water and stabilization of soil from roots. The middle portion of the watershed has fewer anthropogenic influences, most likely due to the steep terrain (see Figure 3).

The United States Department of Agriculture, Natural Resources Conservation Service Soil Survey documents dominantly loamy soils in the watershed that contributes to the existing culvert (USDA 2021). Alderwood gravelly sandy loam comprises approximately 52 percent of the watershed. Alderwood gravelly sandy loam typically has moderate infiltration rates and moderately well drained soils. These soils are in the upper reaches of the watershed. In the gullies, which were formed during the glacial outwash period, the soils consist of Kitsap silt loam. These soils comprise approximately 22 percent of the watershed, but they dominate within the actual channel and valley. Kitsap silt loam is primarily composed of silts, clay, and very find sands, and drains moderately well. The project-specific geotechnical scoping memo clarifies that the underlying soils at this site are cohesionless and highly susceptible to erosion. See Figure 6 for the soils map

Landslides are mapped in the gullies containing the Kitsap silt loam, providing a supply of sediment sufficient to cause aggradation within the alluvial fan where the project is located (see Figure 4). See Sections 2.7.4 for discussion of aggradation risks for this project. See Section 4.2.3 for discussion on how the proposed design considers additional freeboard to compensate for potential aggradation.

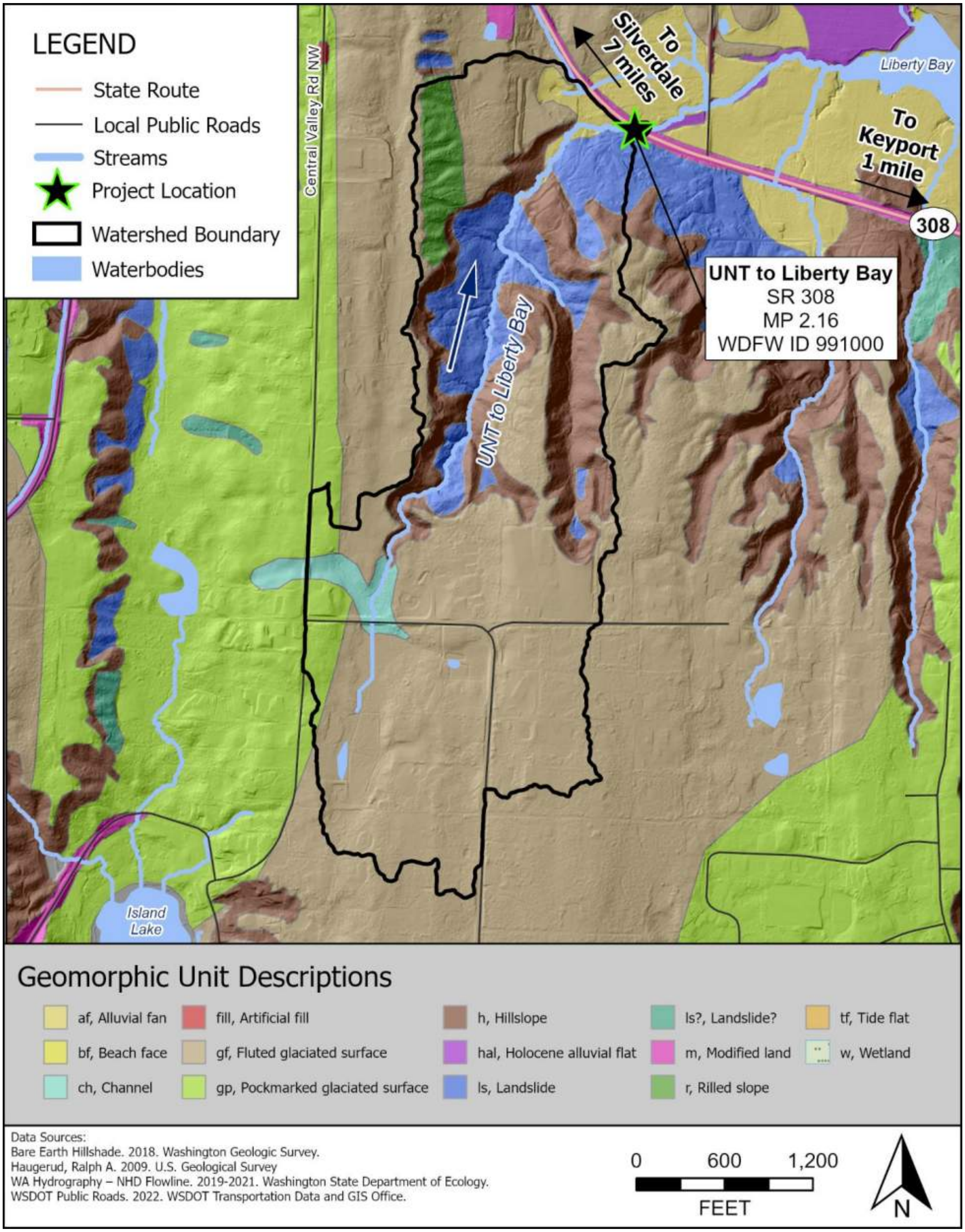

Figure 4: Geomorphic map

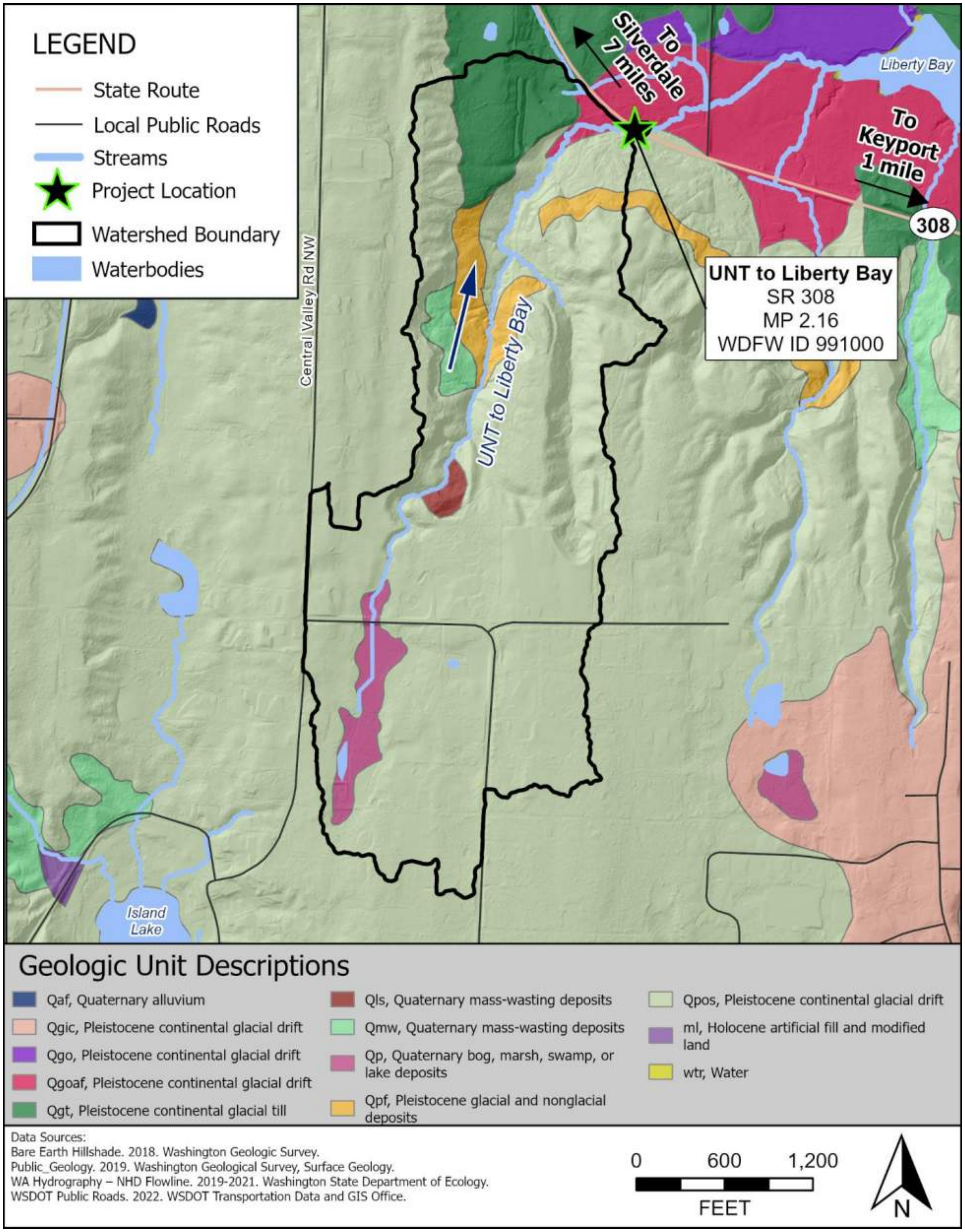

Figure 5: Geologic map

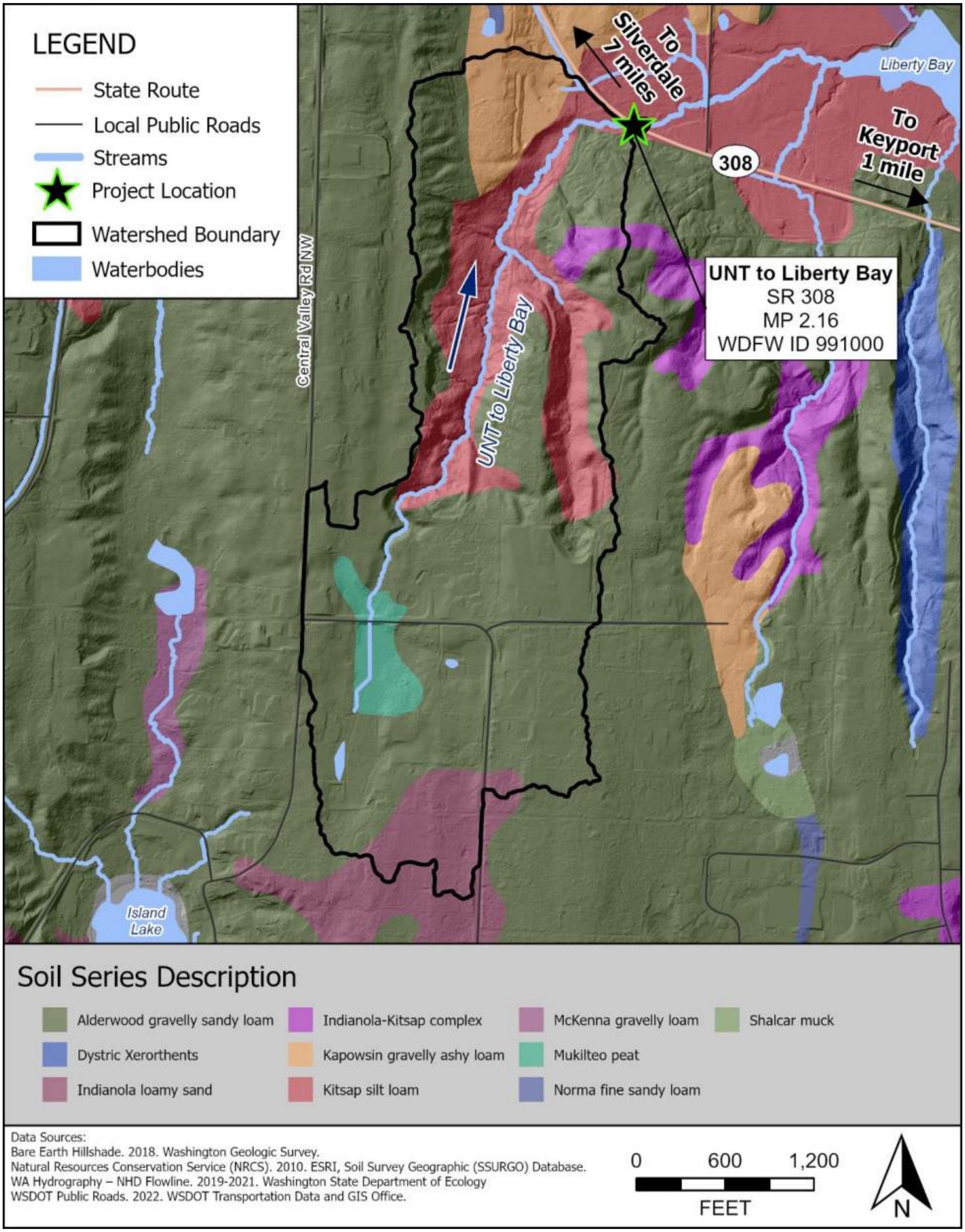

Figure 6: Soils map

2.4 Fish Presence in the Project Area

Table 2 lists the salmonid species documented in the UNT to Liberty Bay downstream of the existing SR 308 crossing. Coastal cutthroat trout (*Oncorhynchus Clarki clarki)* and fall chum salmon (*Oncorhynchus keta*) have been documented within the UNT downstream of the culvert (WDFW 2021a), while coho salmon (*Oncorhynchus kisutch)*, winter steelhead (*Oncorhynchus mykiss)*, and resident trout *(Oncorhynchus mykiss)* are presumed to be in the unnamed stream, indicated by the Reduced Survey Full Survey identifying stream characteristics and habitat features (WDFW 2021b). Information was gathered from the WDFW Fish Passage and Diversion Screening Inventory Database report (WDFW 2021a).

Table 2: Native fish species potentially present within the Unnamed Tributary to Liberty Bay (WDFW 2021)

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coastal Cutthroat Trout (Oncorhynchus Clarki clarki)	Documented	WDFW	Not listed
Fall Chum Salmon (Oncorhynchus keta)	Documented	WDFW	Not listed
Coho Salmon (Oncorhynchus kisutch)	Presumed	WDFW	Not listed
Steelhead (Oncorhynchus mykiss)	Presumed	WDFW	Threatened
Resident Trout (Oncorhynchus mykiss)	Presumed	WDFW	Not listed

2.5 Wildlife Connectivity

Wildlife connectivity will only be included in the FHD if wildlife connectivity is included as a part of the project.

2.6 Site Assessment

2.6.1 Data Collection

David Evans and Associates, Inc. (DEA) visited the project site on November 29, 2021, to conduct a stream assessment and collect data to support preliminary design. DEA collected two bankfull width (BFW) measurements and a pebble count within the reference reach, a 105-foot segment of stream that begins approximately 50 feet upstream of the culvert inlet and extends to a point approximately 155 feet upstream of the culvert inlet (see Figure 7). The channel downstream of the culvert was not suitable for a reference reach because there was evidence of scour, bank erosion, and channel incision directly downstream of the culvert for about 200 feet. The measurements taken within the reference reach indicated an average BFW of 6.5 feet. The D_{100} and the D_{50} were determined to be 2.5 inches and 0.8 inches, respectively. See the Hydraulics Field Report in Appendix B for a more thorough description of this site visit. Sections 2.7.2 and 2.7.3 include further discussion of BFW measurements and pebble counts.

The next site visit was on December 17, 2021, and included WDFW staff along with Suquamish Tribal representatives (collectively referred to as “co-managers”), as well as staff from WSDOT. The purpose of this meeting was to establish concurrence on the BFW measurements used to inform the hydraulic opening width. In addition to the BFW’s measured by DEA during the November 29 site visit, the stream design team and the co-managers added two additional BFW measurements. Section 2.7.2 includes further discussion of the results of this site visit.

In January 2022, WSDOT provided a topographic survey of the UNT to Liberty Bay from approximately 250 feet downstream of SR 308 to approximately 310 feet upstream (see Appendix D). The survey included important features such as large woody material (LWM), significant trees, and infrastructure in the vicinity of the crossing.

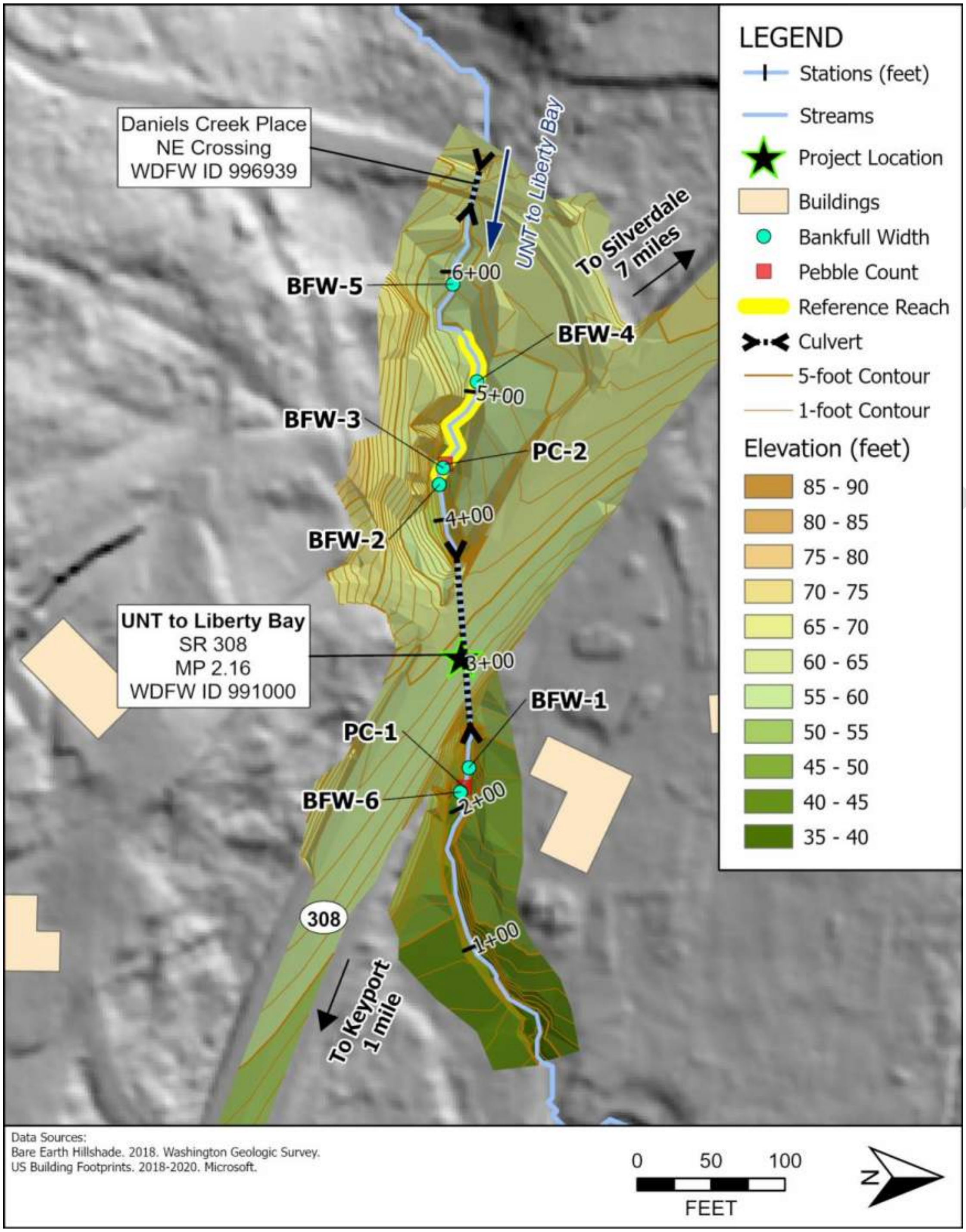

Figure 7: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The November 29, 2021, site visit included exploration of the channel upstream of the crossing, between the SR 308 crossing and the upstream crossing at Daniels Creek Place NE (WDFW ID 996939, see Figure 7). The channel is relatively confined and has steep channel banks on both sides and a steep hillslope above the right bank (see Section 2.7.2). The channel banks and overbank areas are well vegetated (see Figure 8), but because the channel is relatively confined and because of lack of channel complexity, suitable fish habitat in this reach is limited (see Sections 2.6.3 and 2.6.4 for further discussion). Gravels and small cobbles were observed within this reach, but there were very few fines (see Section 2.7.3). No high-water marks were observed in the overbank areas. Several small pieces of woody material were observed within the channel, forming small step-pools (see Figure 9). No significant sediment deposits were observed immediately upstream of the existing culvert, and the culvert was not embedded on the upstream end. There is no evidence of maintenance activity such as dredging or sediment removal in the upstream end of the channel.

The existing crossing is a 114-foot-long, 30-inch-diameter concrete culvert at a 1.9 percent gradient. WSDOT provided 1929 as-builts that detail the installation of this structure, but these as-builts do not specify any invert elevations and do not provide a profile for this structure. The depth of fill above the top of the culvert is approximately 9 feet. The culvert is at a 54-degree skew with respect to a perpendicular orientation with the roadway. The culvert inlet is well-aligned with the flow (see Figure 10). There are existing residential driveways on either end of the crossing. Various other infrastructure at this crossing includes mailboxes, utility lines, utility boxes, power poles, and a top-secret underground fiber optic line associated with the various naval military bases in the region.

There is a 1.5-foot drop on the downstream end of the culvert along with a circular scour hole that is approximately 6 feet in diameter (see Figure 11). The bottom of the scour hole is approximately 0.5 foot below the surrounding channel bed. Aside from the scour hole, no significant pools were observed in this reach. The downstream end of the crossing is more restricted than the upstream end due to adjacent infrastructure. There is a cluster of utility boxes along the road embankment, far up the right bank of the creek channel, and a house within 50 feet of the left top of bank. The vegetation at the downstream end provides less canopy cover than upstream, and the channel is also straighter on the downstream end of the crossing (see Figure 12). The landowners on the downstream end of the crossing have installed some riparian plantings along an incised streambank adjacent to their property. This bank erosion is caused by a mid-channel stump that is redirecting flow towards the left bank (see Figure 13). The WSDOT survey crews recently removed some of the dense undergrowth that was encroaching into the channel to improve sightlines and site access.

Overall, fish habitat at this site is limited. There are very few channel-complexity features capable of providing refuge from velocity or predators for juvenile or migrating fish. Coastal cutthroat trout could use this stream, but use by larger salmonid species would be dependent on seasonal flows.

Figure 8. Upstream characteristics (Sta. 3+80)

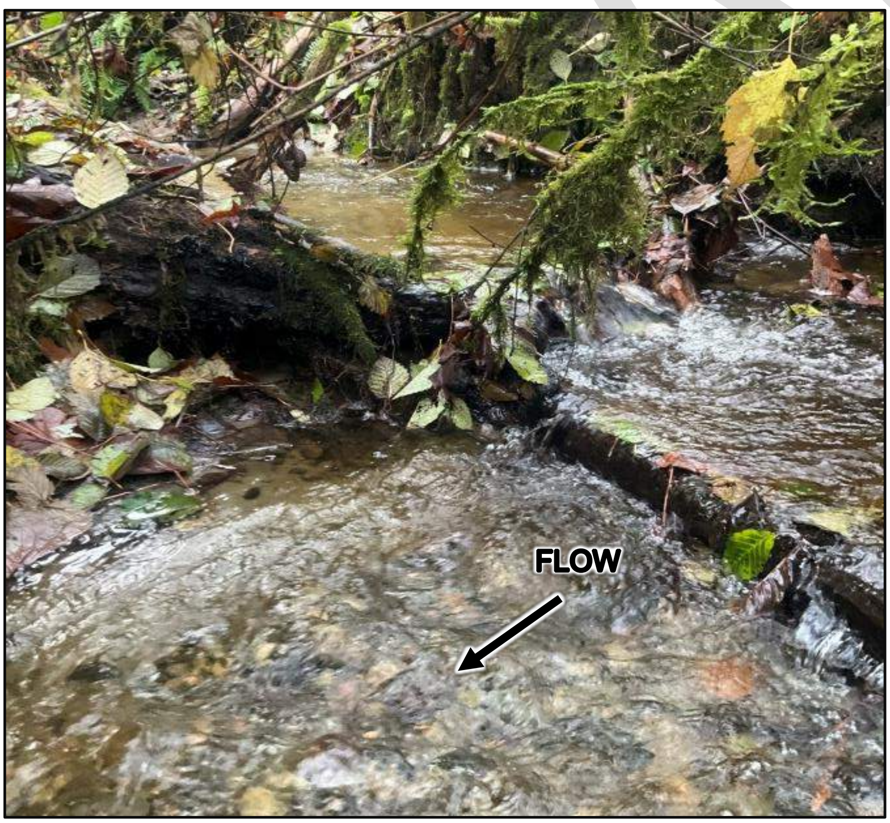

Figure 9. Woody material in upstream channel (Sta. 4+50)

Figure 10. Culvert inlet (Sta. 3+80)

Figure 11. Culvert outlet (Sta. 2+50)

Figure 12. Downstream characteristics (Sta. 1+80)

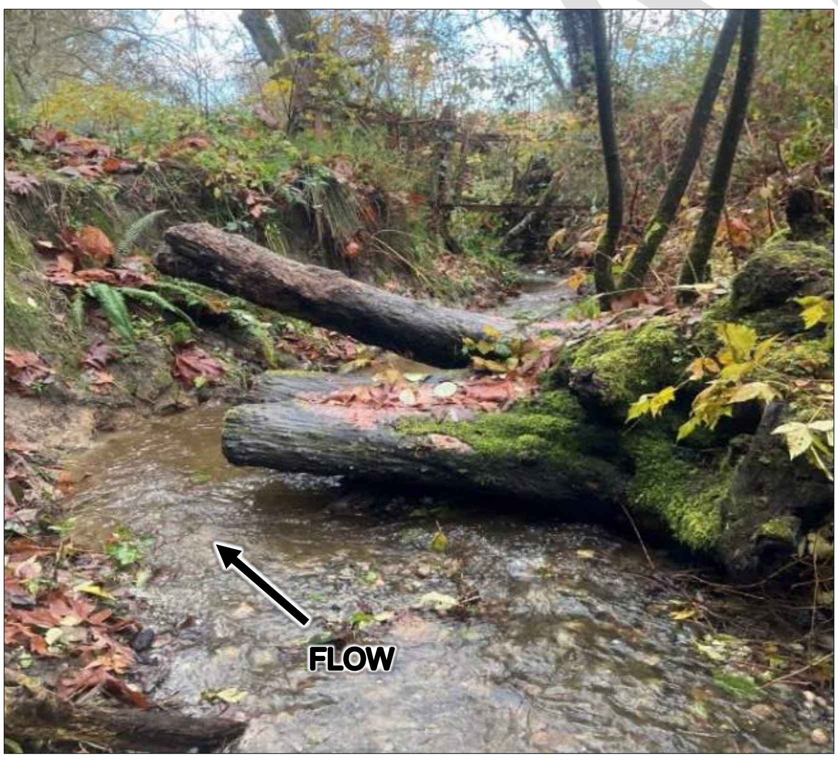

Figure 13. Mid-channel stump in downstream channel (Sta. 1+90)

2.6.3 Fish Habitat Character and Quality

The 2004 WDFW Level A Culvert Assessment Report lists the existing structure at SR 308, MP 2.16 as a 0 percent passable structure due to a 2.43 percent slope (WDFW 2004a). The recent WSDOT survey more accurately determined the existing culvert slope to be 1.9 percent. Additionally, there is a 1.5-foot drop at the culvert outlet, which exceeds the maximum 9.5-inch water surface drop for fish passable culverts specified in the WDFW Fish Passage Inventory, Assessment, and Prioritization Manual (WDFW 2019).

DEA biologists visited the site on December 1, 2021, to assess fish habitat character and quality. Fish habitat in the reach upstream of the culvert is present, though not abundant. Deciduous trees, and a dense shrubby understory line the channel, keeping the stream cool and covered during the summer months. Immediately upstream of the culvert, the only rearing habitat is undercut banks, which provide refuge for rearing coho salmon and both coastal cutthroat and resident rainbow trout. Approximately 50 feet upstream of the culvert, the stream exhibits more LWM and pools for juvenile salmonids, and a few spawning gravels for adult salmonids. The primary limiting factor in the upstream reach is insufficient depth of water for adult salmonids, which rely on increased flows for upstream migration and spawning. There were no documented wetlands upstream of the crossing.

Downstream of the culvert, sparse vegetation cover and the absence of pools provide little rearing habitat for salmonids. This relatively straight, shallow plane-bed section of the stream does provide substrate to accommodate spawning for smaller salmonids, such as coastal cutthroat trout and resident trout, but the shallow water depth still limits the suitability of this reach for large adult salmonids. Even smaller salmonids would likely need to move further downstream to find suitable rearing habitat.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

Upstream of the culvert, the riparian area consists of mid-sized deciduous trees, including black cottonwood (*Populus trichocarpa*), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*). A moderately dense shrubby understory of native vegetation, including salmonberry (*Rubus spectabilis) and swordfern (Polystichum munitum*), provides 75 percent cover to the stream channel and a source of woody material for channel stability and habitat diversity. English ivy (*Hedera helix*) was observed growing on a number of mature trees but was the only invasive species observed during the site visit (see Figure 14). The LWM is not likely to be transported due to the sinuosity and small size of this stream. Though woody material is present, the site visit did not discover any woody material larger than 12 inches in diameter within the stream. Future LWM recruitment through fallen tree branches and trees is possible, though no obvious candidates were observed. The number of pools is very limited, though undercut banks can provide refuge (see Section 2.6.3). The December 1, 2021, site visit did not note any beaver activity.

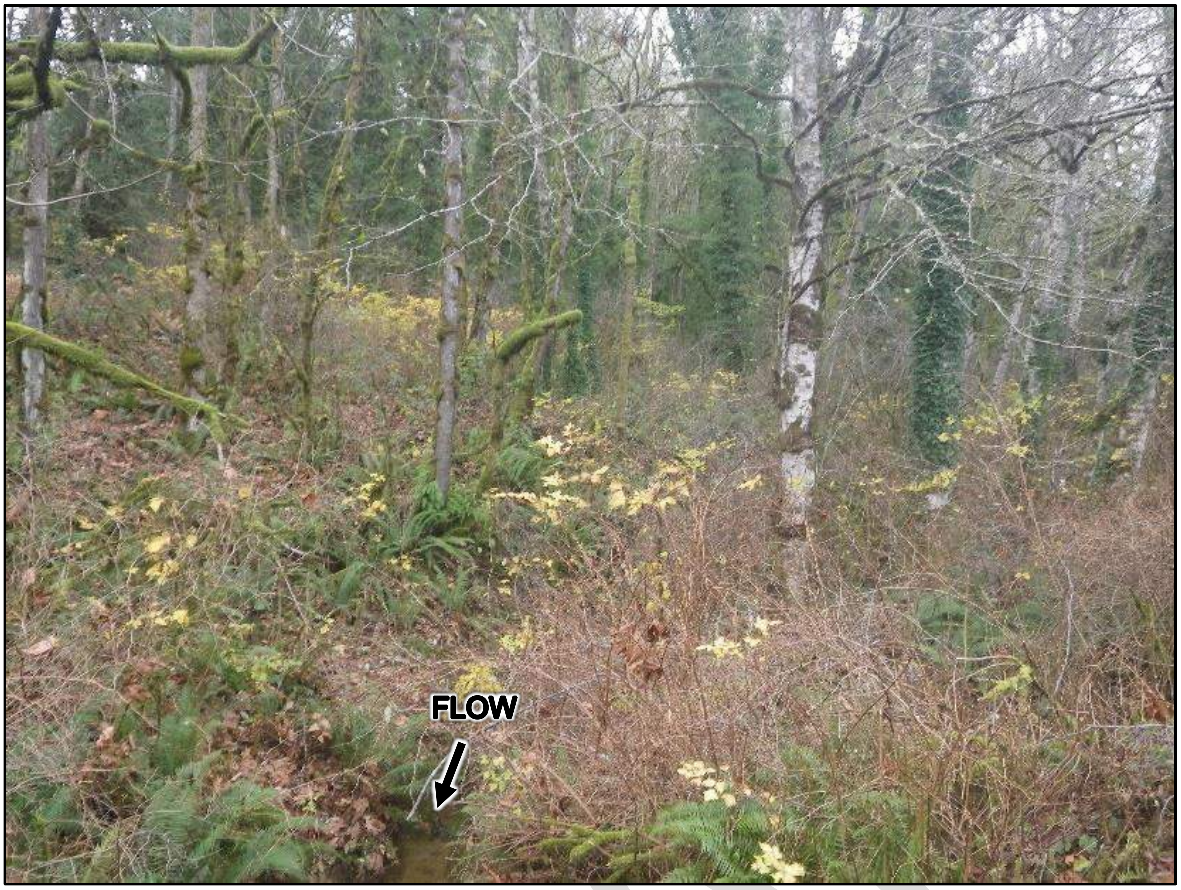

Figure 14: Riparian vegetation upstream (Sta. 3+80)

Downstream of the culvert, the riparian area has been highly modified with lawn, pasture, and other landscaping, and the stream is less shaded than upstream. In this reach, riparian vegetation consisting of bigleaf maple, red alder, and western redcedar (*Thuja plicata*) trees provide shade only for approximately 15 percent of the stream (see Figure 15). Salmonberry, swordfern, trailing blackberry (*Rubus ursinus*), and Himalayan blackberry is the predominate understory vegetation and provide minimal stream cover outside the immediate vicinity of the culvert and roadway. English ivy was also observed growing on mature trees within the downstream reach. A mid-channel rootwad 100 feet downstream of the culvert is redirecting the stream and causing erosion on the left bank. The rootwad does provide an area of refuge for migrating adult salmonids and for rearing juvenile salmonids during higher flows, but it does not interact with the low-flow channel sufficiently to provide primary habitat.

Figure 15: Riparian vegetation downstream (Sta. 2+50)

No boulders or cobbles greater than 5 inches were documented during the site visit, either upstream or downstream of the culvert.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of the UNT to Liberty Bay.

2.7.1 Reference Reach Selection

The reference reach is a 105-foot segment of stream that begins approximately 50 feet upstream of the culvert inlet and extends to a point approximately 155 feet upstream of the culvert inlet (see Figure 7). During the site visit on December 17, 2021, concurrence was obtained from WDFW and the Suquamish Tribe on the location of the reference reach.

The reference reach exhibits a combination of gravel and cobble plane-bed sections interspersed with step-pool features forced by small woody material. The step heights are generally 6 inches or less, and are spaced approximately 25 feet to 35 feet apart (see Figure 16 and Figure 17). The small woody material does not have an impact on channel width. The pool features were filled with coarse to fine sand and very few fines. No boulders were observed during the site visit.

The reference reach is relatively confined, having a steep hillslope with no overbank areas on the south side of the channel (i.e., the right bank looking downstream). There is some flat overbank area on the north side of the channel (i.e., the left bank looking downstream) that is potentially accessible to flood flows. The channel banks are well vegetated and do not show signs of recent erosion (see Figure 18). These characteristics indicate that the natural channel-forming processes have established a relative equilibrium within the reference reach. However, there is evidence that the reference reach experienced channel incision in the past due to sediment supply reduction caused by the upstream culvert at Daniels Creek Place NE (see Sections 2.7.4, 4.1.1, and 7.2). There was no evidence of scour or excessive deposition at the upstream end of the existing culvert crossing at SR 308.

The 3.8 percent slope of the reference reach is steeper than the channel downstream of the culvert, which flattens to 2 percent (see Figure 29 in Section 2.7.4 for the watershed-scale longitudinal profile).

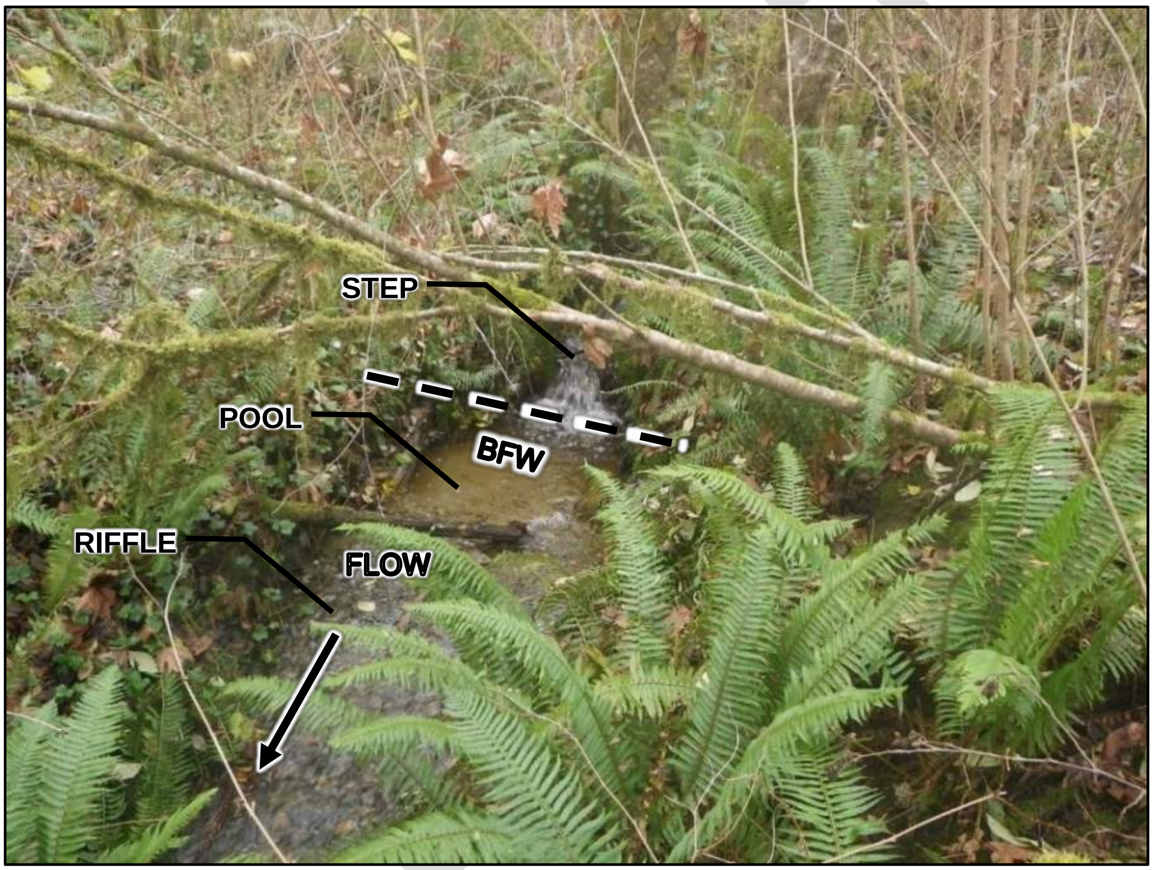

Figure 16: Reference reach, looking upstream (Sta. 5+25)

Figure 17: In-channel woody material (Sta. 4+50)

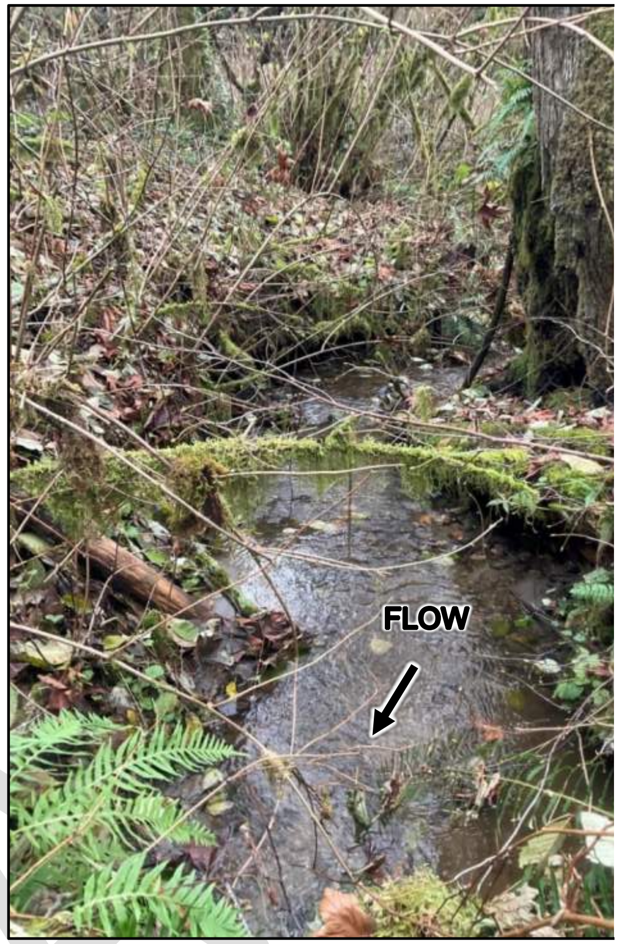

Figure 18: Well-vegetated banks (Sta. 4+25)

The channel downstream of the culvert is not suitable for a reference reach based on evidence of scour, bank erosion, and channel incision directly downstream of the culvert for about 200 feet (see Figure 19) that may have been caused by channel modifications from adjacent landowners that straightened the channel. Farther downstream, the channel exhibits less incision but also appears to have been widened as a result of human activities.

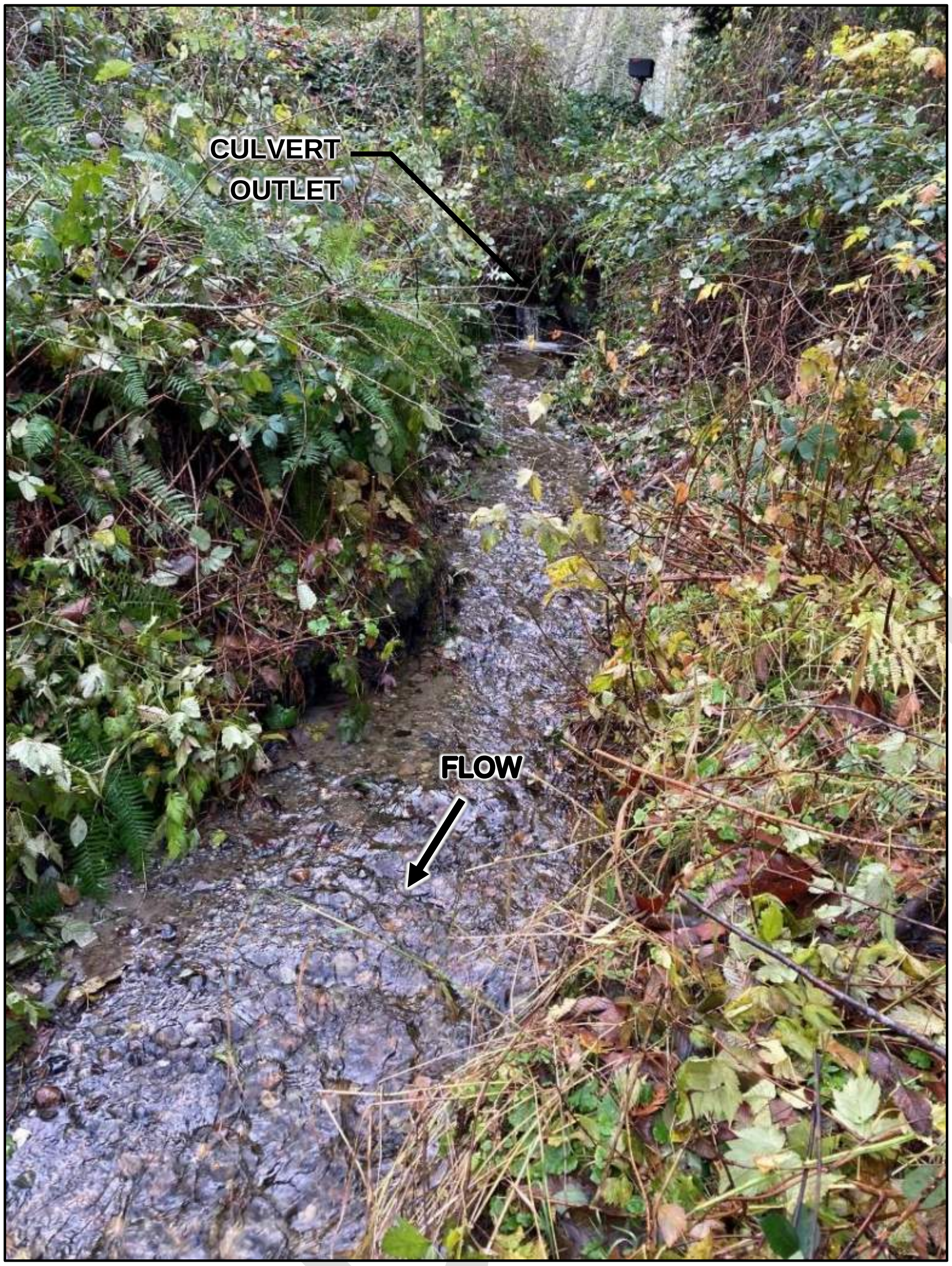

Figure 19: Channel downstream of culvert is straight, with steep banks, and is incised approximately 1.5 feet to 2 feet (Sta. 2+25)

2.7.2 Channel Geometry

The 2-year recurrence interval is typically used as an estimate for the bankfull flow; i.e., the 2-year flow will typically fill the bankfull channel or slightly exceed the channel capacity. However, bankfull width measurements in the field rely on geomorphological indicators such as slope breaks because 2-year flow depths are typically unknown during initial site visits.

For this channel, the top of bank was identified by an inflection point in the slope that was generally 2 feet to 4 feet above the existing channel bed. The banks are steep but well-vegetated upstream of the culvert (see Section 2.6.2). Hydraulic modelling results produced after the site visit indicate flow depths for the 2-year of approximately 1.0 to 1.5 feet, which is below the measured bankfull depth (see Appendix H for SRH-2D model results). The 0.5-foot variability in the modelled bankfull depths are due to natural variations in the surface topography such as pools, riffles, and varying channel slopes throughout the modelled reach.

This discrepancy between the 2-year flow depths and the bankfull channel geometry is due to channel incision, which is likely caused by an upstream culvert that blocks sediment transport (see Section 2.7.4). The loss of sediment supply has caused the channel adjacent to the crossing to become incised, which drops the 2-year water surface elevation below the top-of-bank topography. The proposed channel will be designed with floodplain benches at bankfull depth so that the 2-year will fill the channel banks (see Section 4). See Section 3 for verification of the hydrology inputs used to inform this analysis.

The reference reach would actively degrade but the existing SR 308 culvert provides grade control and prevents degradation. The upstream culvert (WDFW ID 996939) at Daniels Creek Place NE is restricting sediment supply, preventing aggradation from occurring within the reference reach. Thus, the reference reach is in a state of arrested degradation (Stage IIIs), according to the stream evolution model depicted in the document titled *Providing Aquatic Organism Passage in Vertically Unstable Streams* (Castro and Beavers 2016). The rest of the system appears to be in a state of degradation and widening (Stage IV).

The reference reach is a singular plane-bed channel with well-defined channel banks. Channel banks were at an approximate slope of 1:1. At the time of the BFW measurements, the water depth was approximately 3 inches to 6 inches. There are several sharp bends within the reference reach, often forced by living trees adjacent to the stream channel. Channel bends are spaced at approximately 15 feet to 25 feet. The channel thalweg generally follows the toe of a steep hillslope on the right bank that confines the channel. The left bank at the upstream end of the reference reach has approximately 100 feet of floodplain between the stream and the roadway embankment. The channel becomes more confined closer to the upstream end of the existing culvert. The average slope of 3.8 percent through the reference reach was used to determine allowable slopes for the proposed channel grading (see Figure 29 in Section 2.7.4 for the watershed-scale longitudinal profile).

The stream assessment initially included four BFW measurements in the assessed reach, two of which were within the reference reach. Figure 20 and Figure 21 show the two BFW measurements within the reference reach, which the co-managers agreed upon.

Figure 20: BFW-3 measurement of 6 feet measured within the reference reach approximately 60 feet upstream of the culvert (Sta. 4+15)

Figure 21: BFW-4 measurement of 7 feet measured within the reference reach approximately 125 feet upstream of the culvert (Sta. 5+00)

Table 3 summarizes the BFW measurements, which range from 4.5 feet to 8.5 feet. The measured BFWs were discussed with the co-managers during the site visit on December 17, 2021. The co-managers did not concur with one of the initial BFW measurements within the reference reach (BFW-2), which was excluded from the BFW average because it was under the influence of the existing culvert. The co-managers added two additional BFW measurements beyond the reference reach (BFW-5 and BFW-6) for inclusion in the BFW average (see Figure 7 in Section 2.6.1 for a map that shows the BFW measurement locations). The inclusion of these new measurements increased the average BFW to 7.3 feet. However, during the site visit the co-managers preferred an average BFW of 7.5 feet. This average BFW measurement is used to size the minimum hydraulic opening and determine the proposed channel width for the project. With an average bankfull depth of 1.2 feet, the bankfull width-to-depth ratio is approximately 6.25. Figure 22 shows the surveyed channel cross sections at all of the BFW measurement locations included in the BFW average.

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert)	Concurrence notes
1	4.5	No	30 feet downstream	No concurrence required.
2	7	No	45 feet upstream	Stakeholder removed on 12/17/2021.
3	6	Yes	60 feet upstream	Stakeholder concurred on 12/17/2021.
4	7	Yes	125 feet upstream	Stakeholder concurred on 12/17/2021.
5	7.5	Yes	210 feet upstream	Stakeholder added on 12/17/2021.
6	8.5	Yes	50 feet downstream	Stakeholder added on 12/17/2021.
Average	7.3			
BFW Concurrence to be used in design – 7.5 ft				

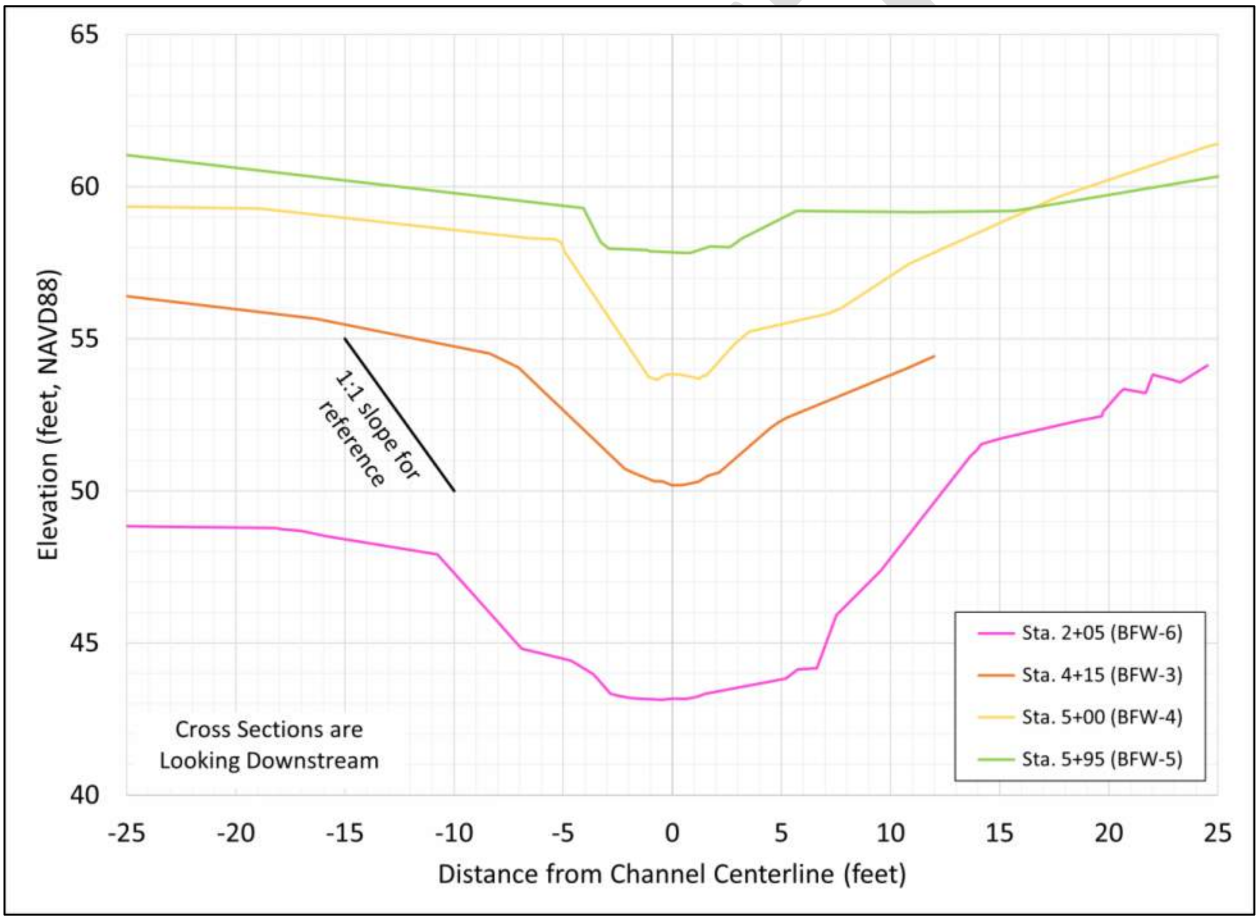

Figure 22: Existing cross-sections at measured BFW locations within the reference reach

2.7.2.1 Floodplain Utilization Ratio

The hydraulic modeling results were used to determine the floodplain utilization ratio (FUR) upstream and downstream of the existing crossing. The FUR was determined from the ratio of the 100-year water surface extents to the measured bankfull width of 7.5 feet (see Section 2.7.2). Backwater at the upstream end of the existing culvert was removed by artificially increasing the capacity of the culvert in the HY-8 model. The existing 30-inch-diameter round culvert was increased to a 30-inch rectangular box culvert that has sufficient capacity to convey the 100-year peak flow without causing any backwater. The average FUR for all locations measured is 2.1, indicative of a confined stream. Table 4 provides the flood-prone width (FPW) and FUR for all cross sections shown in Figure 23.

Table 4: FUR determination

Station	FPW (ft)	2-year flood extents (ft)	FUR	Confined /unconfined	Included in average FUR determination
DS - STA 0+40 (A)	25.5	10.0	2.5	Confined	Yes
DS - STA 1+30 (B)	9.8	5.3	1.9	Confined	Yes
DS - STA 2+05 (C)	10.0	7.7	1.3	Confined	Yes
US1 - STA 4+15 (E) (reference reach)	13.0	9.0	1.4	Confined	Yes
US2 - STA 5+00 (F) (reference reach)	9.7	5.2	1.9	Confined	Yes
US3 - STA 5+95 (G)	15.3	11.3	1.4	Unconfined	Yes
Average	**13.9**	**8.1**	**1.7**	**Confined**	**Yes**

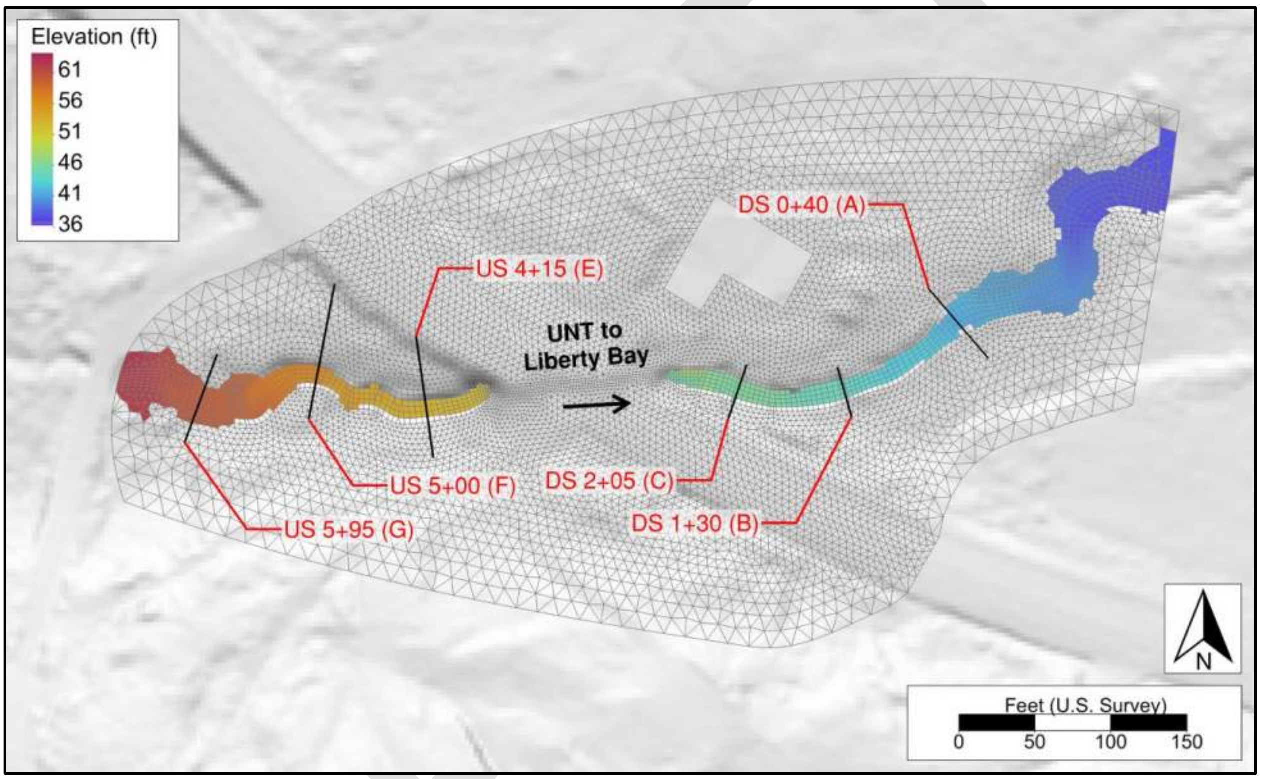

Figure 23. FUR locations

2.7.3 Sediment

Two Wolman Pebble Counts (PCs) were conducted at this site—one downstream of the culvert and one upstream of the culvert. The upstream pebble count is within the reference reach. See Figure 7 in Section 2.6.1 for pebble count locations. Additional pebble counts within the reference reach were not necessary given the homogeneity of sediment within the stream. The channel bed material upstream and downstream of the culvert consists of sand with coarse gravels and small cobbles observed at shallower sections where flow velocity is higher. An armor layer was not present. The upstream and downstream pebble counts were very similar in gradation. Very few fines were observed. No boulders were observed during the site visit.

PC-1 was conducted along a length of stream approximately 30 feet and 50 feet downstream of the existing culvert outlet. The sediment here consisted of coarse sands, gravels, and small cobbles of 3.5 inches or less (see Figure 24 and Figure 25). In general, the coarse material at this location was more exposed than within the reference reach, where much of the coarser material was overlain with sand.

Figure 24. PC-1 sediment with gravelometer

Figure 25. PC-1 sediment in hand

PC-2 was conducted within the reference reach, at a location approximately 55 feet to 65 feet upstream of the existing culvert inlet. This location exhibited a gravel and cobble plane-bed morphology with few fines. The sediment here consisted of coarse sands, gravels, and small cobbles of 2.5 inches or less (Figure 26 and Figure 27). The coarse material was overlain with sand in much of the reference reach.

Figure 26. PC-2 sediment with gravelometer

Figure 27. PC-2 sediment in hand

Table 5 and Figure 28 show the sediment distribution results for both pebble counts.

Table 5: Sediment properties near the project crossing

Particle size	Pebble Count 1 diameter (in)	Pebble Count 2 diameter (in)	Average diameter for design (in)
Included in average?	Yes	Yes	
D_{16}	0.2	0.2	0.2
D_{50}	0.7	0.8	0.8
D_{84}	1.4	1.6	1.5
D_{95}	2.1	2.1	2.1
D_{100}	3.5	2.5	3.5

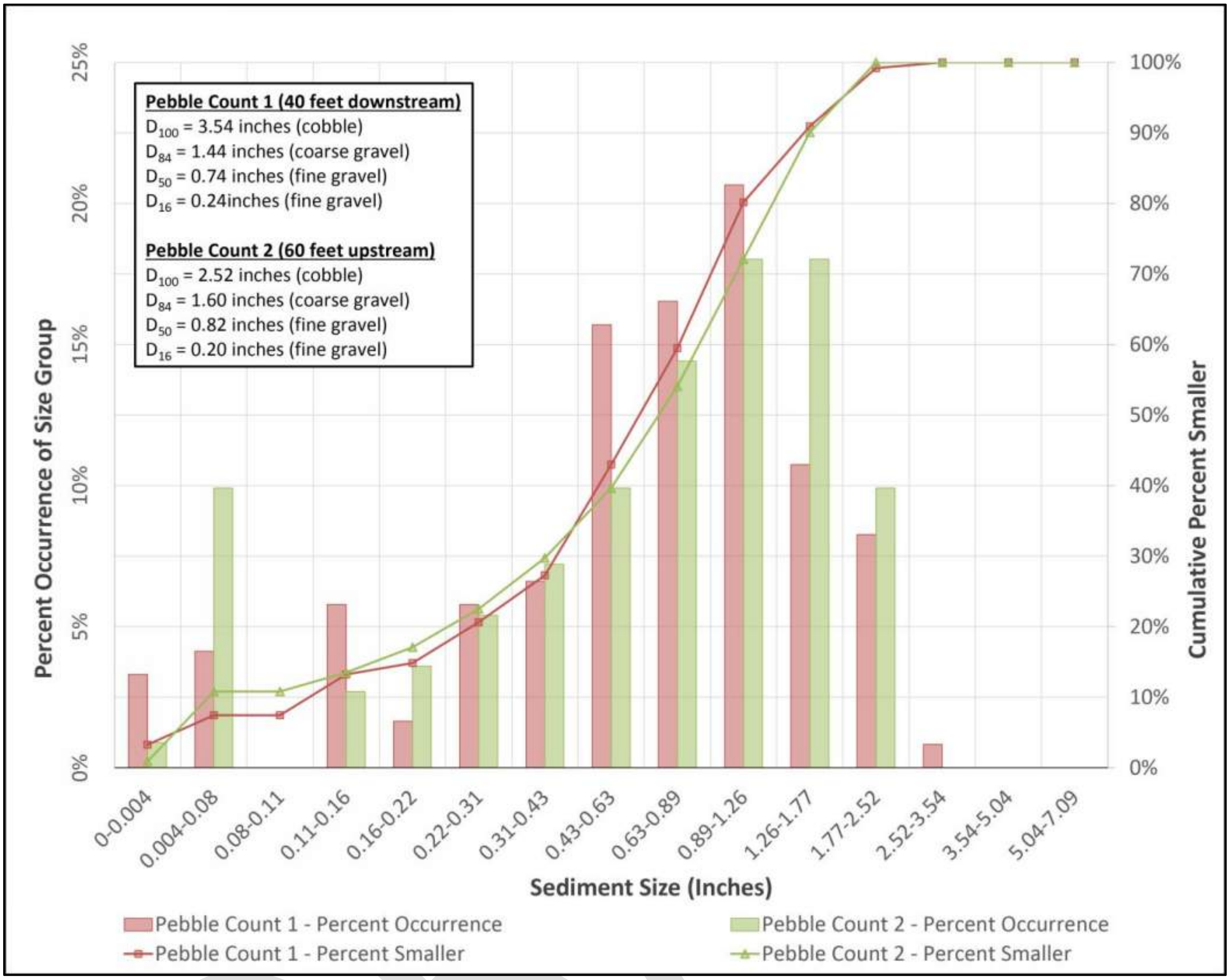

Figure 28: Sediment size distribution

2.7.4 Vertical Channel Stability

No active vertical incision was observed upstream of the culvert. However, the presence of well-vegetated but steep channel banks, along with modelled bankfull depths that do not fill the bankfull channel (see Section 3) provides evidence that channel incision occurred in the past, but was arrested by the SR 308 culvert, thus allowing the channel banks to revegetate and stabilize. The channel does not appear to be either aggrading or degrading, and the channel banks appear well vegetated and do not have any signs of erosion or lateral migration. This section of the channel is stable and woody material is not present. The reference reach appears to be in a state of arrested degradation (Stage 3s), while the rest of the system appears to be in a state of degradation and widening (Stage IV) according to the stream evolution model depicted in the document titled *Providing Aquatic Organism Passage in Vertically Unstable Streams* (Castro and Beavers 2016).

The channel downstream of the culvert appears to have been straightened by adjacent development, and the resultant oversteepening caused it to readjust and incise to a stable slope, resulting in a headcut in the downstream channel. In this downstream reach the channel slope decreases, and vertical incision of 1.5 feet to 2 feet begins at the culvert outlet, extending downstream for about 200 feet (see Figure 29). A 2-foot-deep to 3-foot-deep scour hole was observed at the downstream end of culvert (see Figure 30). Thus, the existing culvert is acting as a vertical grade control. The upstream culvert crossing (WDFW ID 996939) is inhibiting sediment continuity through the project reach and is exacerbating erosion problems in the downstream channel due to a decreased sediment supply (see Figure 29).

The existing SR 308 crossing is located within an alluvial fan, where sediment from the steeper transport reaches upstream tend to settle out as the flow velocity decreases upon contact with the milder slopes at the toe of the hillslope. Indeed, the fish passage barriers upstream and downstream of the project location do show evidence of aggradation. Approximately 500 feet downstream of the project culvert, there is a 24-inch corrugated metal pipe culvert (WDFW ID 996938) at Virginia Loop Road, and approximately 300 feet upstream of the project culvert, there is a 24-inch corrugated metal pipe culvert (WDFW ID 996939) at Daniels Creek Place NE. Both of these culverts are embedded by at least half of their diameter (WDFW 2004b; WDFW 2004c). Documented aggradation at both crossings upstream and downstream of the SR 308 crossing provides evidence of sufficient sediment supply within the watershed to cause aggradation at the SR 308 crossing.

Approximately 3 feet of aggradation may be expected at this site when the upstream culvert crossing (WDFW ID 996939) is removed (see Figure 29). It is unknown whether or when the upstream barrier may be removed. The site visits did not include exploration of the channel upstream of Daniels Creek Place NE (WDFW ID 996939) due to very dense vegetation; therefore, information about sediment transport at this PHD stage is limited. See Section 4.2.3 for discussion on how the proposed design considers additional freeboard to compensate for potential aggradation.

The channel immediately downstream of the culvert appears to be in Stage IV (degradation and widening) according to the stream evolution model depicted in the document titled *Providing Aquatic Organism Passage in Vertically Unstable Streams* (Castro and Beavers 2016). Downstream of the 200-foot straightened and incised portion of the stream, the channel has a more natural meandering form and is vertically stable; here the channel evolution is Stage II (floodplain) (Castro and Beavers 2016).

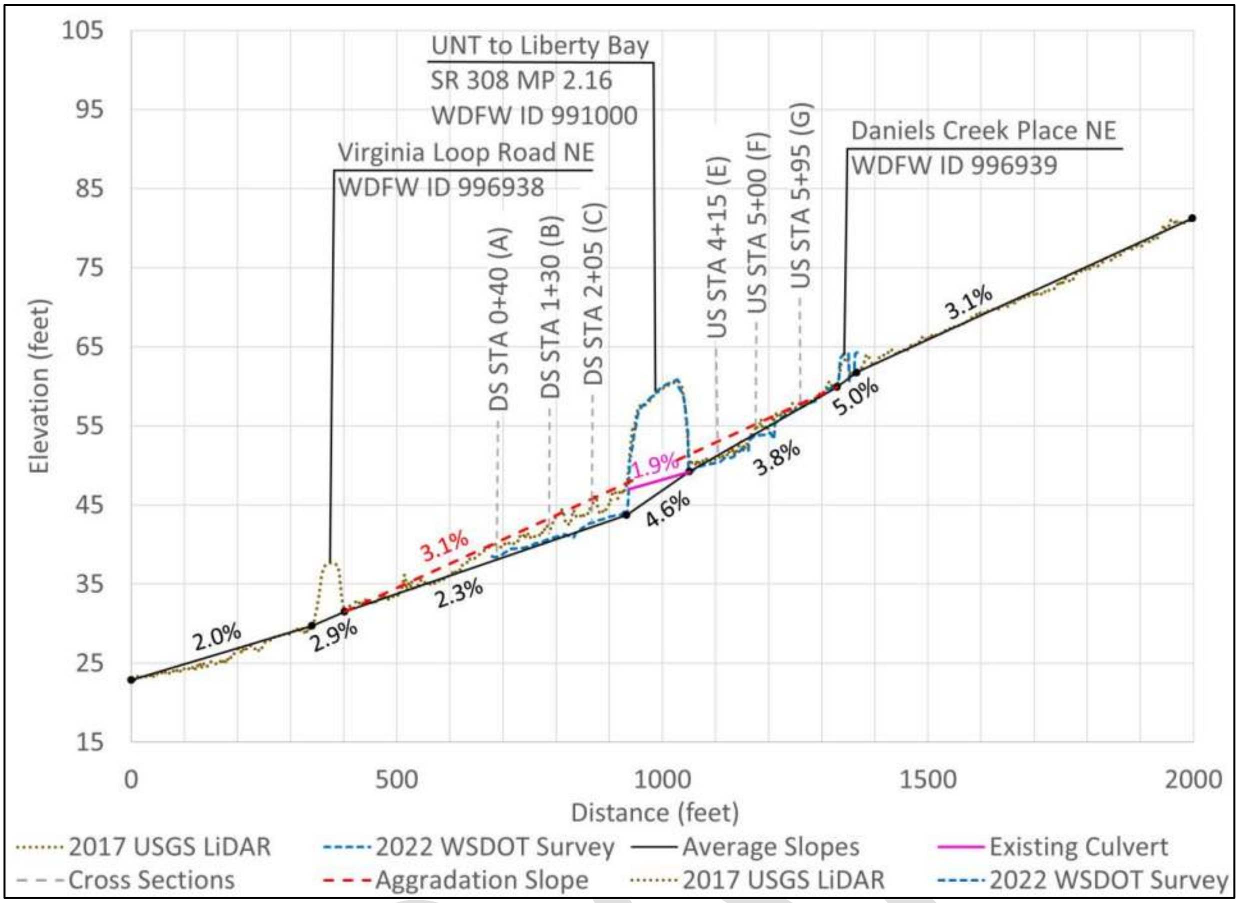

Figure 29: Watershed-scale longitudinal profile

Figure 30: Scour hole at downstream end of culvert (Sta. 2+55)

Section 4.1.3 discusses the proposed longitudinal profile in the reconstructed stream section, which will remove the drop at the downstream end of the existing structure. This design will minimize the probability of long-term vertical instability. See Section 7.2 for a more detailed discussion of long-term vertical channel stability.

2.7.5 Channel Migration

Field observation revealed no evidence of recent lateral migration nor did the LiDAR topography show any longer-term channel migration. The banks are steep but well-vegetated upstream of the culvert (see Section 2.6.2). The meander belt width within the reference reach ranges from 13 feet to 20 feet (see Section 4.1.1 for further discussion). Though the existing SR 308 crossing is located within an alluvial fan, the ability of the channel to meander in the vicinity of the fan is limited by the infrastructure in this area. The upstream culvert crossing (WDFW ID 996939) and the roadway itself prevent the channel from meandering, and effectively reset the channel evolution process of degrading and widening.

It is unlikely that the channel would migrate between the SR 308 crossing and the upstream culvert crossing because of the confined nature of the channel between these two crossings.

There is very little floodplain activation within the reference reach or downstream of the project site between the SR 308 crossing and the downstream barrier at Virginia Loop Road (WDFW ID 996938). Within the reference reach, floodplain engagement is caused by backwater from the existing culvert, which will be removed by the proposed design. See Section 5 for hydraulic modeling results. The existing channel at the crossing location is likely at low risk for channel migration based upon preliminary desktop reconnaissance, but this conclusion cannot be confirmed until detailed geotechnical data is available to support the assessment and the structure type is known.

The channel downstream of the existing culvert has steep exposed banks. Evidence of channel widening and lateral erosion was limited to a location in the downstream reach where a large stump had created a flow obstruction (see Figure 31). Except for this one location of erosion, the channel banks do not appear to be actively eroding. The project-specific geotechnical scoping memo clarifies that the underlying soils at this site are cohesionless and highly susceptible to erosion.

Figure 31: Channel widening and bank erosion due to flow obstruction (Sta. 2+00)

Approximately 250 feet downstream of the culvert, the channel appears over-widened (see Figure 32), likely the result of the lack of riparian vegetation and bank erosion from use by stock animals. This over-widening does not appear to be a result of natural channel migration but rather of damage to the stream buffer and banks from landowner activity.

Figure 32: Over-widened channel approximately 250 feet downstream of the culvert (Sta. 0+00)

3 Hydrology and Peak Flow Estimates

There are no streamflow gages located on the UNT to Liberty Bay. The mean annual precipitation for the watershed contributing to the SR 308 crossing is 40.4 inches (PRISM Climate Group 2021). The watershed boundary was delineated using GIS software, resulting in a basin area of 0.31 square miles (see Section 2.2). Typical summer low-flow conditions for this site are unknown, but it is probable that the stream occasionally runs dry during the summer.

The USGS webapp StreamStats (USGS 2016) was used to determine initial peak flows for this stream (see Table 6). Hydraulic modelling using the calculated mean flow values from StreamStats indicated that the flows were lower than what would be expected for the observed channel morphology. Generally, in the absence of calibration data, hydraulic models are calibrated so that the 2-year flow depth is roughly equivalent to the bankfull depth within a given stream. The modelled StreamStats flows resulted in flow depths that did not fill the bankfull channel.

Due to the issues apparent with the StreamStats discharge estimates, MGSFlood (USGS 2016) was also used to determine the peak flows for this stream . The MGSFlood discharge estimates were generally 30 to 50 percent greater than the upper limit of the discharge estimates provided by StreamStats (see Table 6). Hydraulic modelling of the MGSFlood discharge estimates resulted in greater 2-year flow depths of generally 1.5 feet, but this is still below the existing incised channel depth of around 4 feet. This is due to apparent channel incision caused by sediment starvation (see Section 2.7.4). Additional information used to calibrate model results, such as rust lines on structures, scour lines, and evidence of high flow debris, were not evident during the site visit.

To verify the peak flow estimates provided by MGSFlood, a stream gage analysis was performed on an adjacent stream. The Kitsap County Public Utility District maintains the Clear Creek stream gage which is approximately 3 miles southwest of the SR 308 crossing. Clear Creek has a basin size of 3.9 square miles, and is therefore approximately 13 times larger than the watershed contributing to the SR 308 crossing. Both creeks have similar mean annual precipitation (43.8 inches at Clear Creek and 40.4 inches at SR 308), and similar land-use. The Clear Creek stream gage data begins in 2001 and continues through 2022. However, there is a gap in the data from 2003 to 2012. So, 14 years of discontinuous hourly gage data was available for frequency analysis. No quality control documentation was available for the dataset, so it was used in “as-is” condition. The Bulletin 17C procedure in HEC-SSP version 2.2 was used to estimate peak discharge. The result of this analysis estimates a 100-year peak flow of 459 cfs for Clear Creek. Scaling this estimate to the basin area at the SR 308 crossing results in an estimate of 35.3 cubic feet per second (cfs) for the 100 year event, which is less than half of the 100 year peak flow estimate provided by MGSFlood. The MGSFlood peak discharge estimates shown in Table 6 were used for hydraulic modelling as they provide the greatest peak discharge estimate of all hydrologic analysis methods explored. See Appendix M for hydrology calculations.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 84.6 cfs at the 100-year storm event. The projected increase for the 2080 100-year flow is 60 percent, yielding a projected 2080 100-year flow of 135 cfs.

Table 6: Peak flows for unnamed tributary to Liberty Bay at SR 308

Mean recurrence interval (MRI) (years)	StreamStats (cfs)	StreamStats Upper Prediction Interval (cfs)	MGS Flood (cfs)
2	6.45	13.0	**25.0**
10	13.0	27.2	**51.1**
25	16.5	36.0	**62.6**
50	19.1	43.0	**70.2**
100	21.9	50.3	**84.6**
500	28.5	71.2	**160**
Projected 2080 100	45.6	80.5	**135**

4 Water Crossing Design

This section describes the water crossing design developed for SR 308 MP 2.16 UNT to Liberty Bay, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for the UNT to Liberty Bay at SR 308 MP 2.16.

4.1.1 Channel Planform and Shape

The WCDG (Barnard et al. 2013) recommends that a proposed stream channel should have a cross-section, and general configuration that are similar to the existing channel upstream and downstream of the proposed crossing, provided the adjacent channel has not been modified in a way that adversely affects natural stream processes. Existing conditions for the UNT to Liberty Bay were evaluated upstream and downstream of the SR 508 crossing (Section 2.6 and Section 2.7). The average BFW (see Section 2.7.2), based on measurements made in the field and agreeable to the co-managers, is 7.5 feet.

The reference reach is starved for sediment due to the influence of the upstream culvert crossing (WDFW ID 996939, see Section 2.7.4). Consequently, the channel is more incised than it would be under normal sediment transport conditions. The vertical incision within the reference reach has existed long enough to allow the steep channel banks to become well-vegetated (see Section 2.6.2). Flows are notably confined within the channel through this reach. The modeled 2-year flow depths for existing conditions confirm this assessment, because they do not fill the bankfull channel (see Section 3). Depths are generally 1.5 feet or less for the 2-year flow, whereas the channel banks are generally 3 feet to 4 feet above the channel thalweg (see Appendix H for SRH-2D existing conditions model results). The incision within the reference reach is limited due to the grade control provided by the SR 308 crossing (see Section 2.7.4), allowing the reference reach to be in a state of quasi-equilibrium compared to the channel downstream of the SR 308 crossing, which is in a state of degradation and widening (see Section 2.7.5).

The proposed channel shape was determined using a combination of BFW measurements and cross sections within the existing channel. Figure 33 shows the existing cross sections (BFW-3, BFW-4, BFW-5, and BFW-6) used to determine the proposed cross section. BFW-5 and BFW-6 are outside the reference reach, but were included in the BFW average, as discussed in Section 2.7.2. Additional cross sections downstream of the culvert are included for reference purposes.

None of the surveyed cross sections match the proposed cross section exactly, as would be expected. The existing cross section that matches the channel shape of the proposed cross section most accurately is BFW-5. This location is upstream of the reference reach, outside the influence of the hillslope on the right bank, or southern edge, of the stream. Although BFW-3 and BFW-4 within the reference reach do not exhibit floodplain benches, the proposed channel alignment will move the channel away from the hillslope (see Section 4.1.2); therefore, a cross section from a less confined reach is a better representation of how the hydraulics will function in the proposed channel. This cross section for BFW-5 has also experienced less incision than the other sections, which is more representative of the expected morphology for this channel. Hydraulic modeling confirms that the 2-year flow fills the channel banks within the proposed channel (see Appendix H for SRH-2D proposed conditions model results). While this does not match the reference reach, which is incised, the proposed design will provide more engagement with the floodplain and provide more fish habitat in the overbank areas.

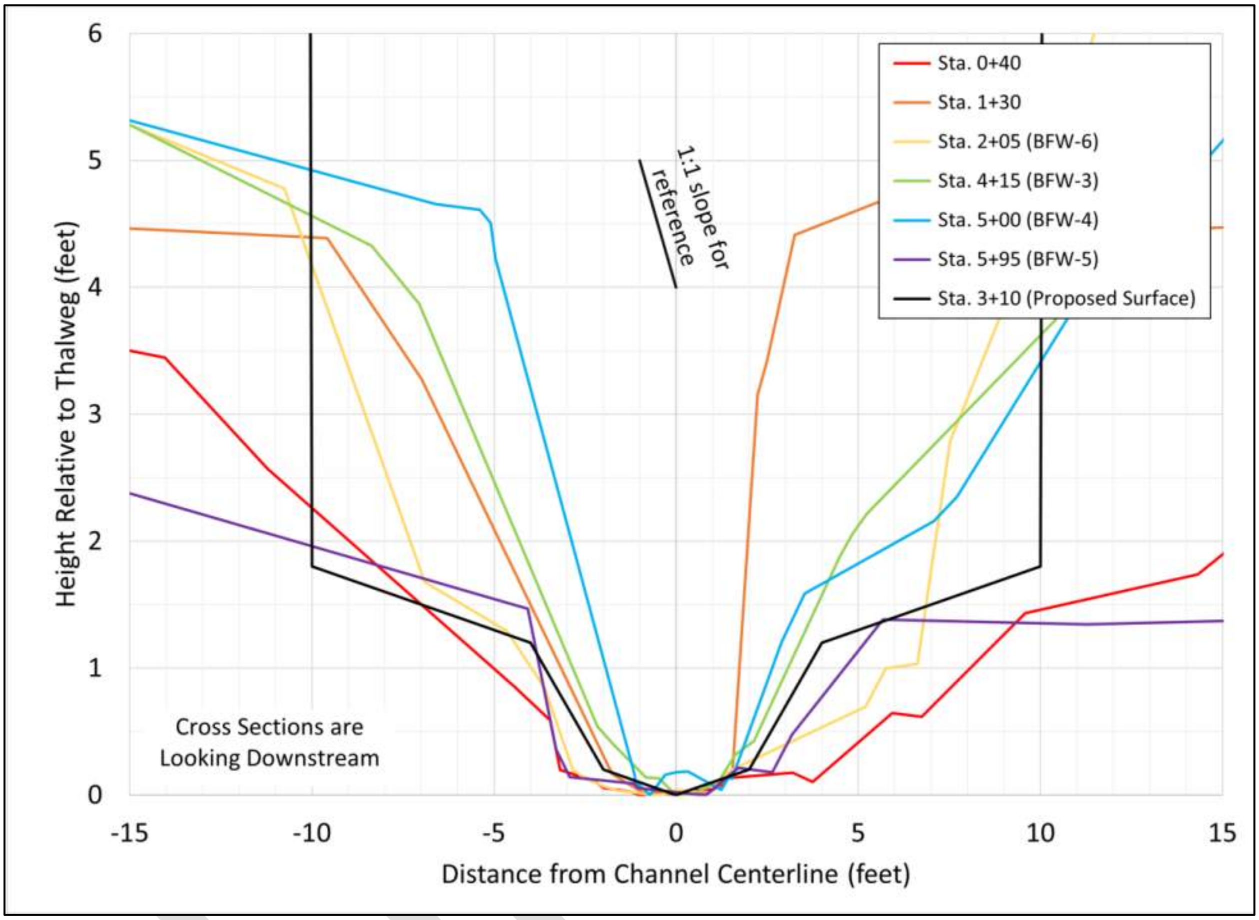

Figure 33: Proposed cross section superimposed with existing survey cross sections

The proposed channel design is based on typical sections that are then influenced by placement of LWM as directed by the engineer in the field. The channel is intended to provide depth and flow velocities that are adequate for use by salmonids across all their life stages. The proposed channel is 8 feet wide, with a 4-foot-wide channel bottom and 1-foot-high channel banks at a slope of 2:1. Beyond the channel banks, there are 2.5-foot-wide floodplain benches on either side of the channel (see Figure 34). Within the structure the floodplain benches are 6.0 feet wide. Beyond the floodplain benches, the overbank slopes match existing grade with a 2:1 cut slope, or a 50:1 fill slope, where applicable. This channel shape will match the channel morphology this reach is expected to develop over time, once the upstream barrier at Daniel Creek Place NE is removed and aggradation is allowed to continue through the SR 308 crossing (see Sections 2.7.4 and 4.2.3). Placement of large wood and boulder clusters will help maintain channel morphology if either aggradation or degradation occurs (see Section 4.3.2).

Outside of the proposed structure the 2-year water surface elevation (WSE) overtops the channel banks, but within the proposed structure the 2-year WSE is within 0.2 feet of the top of channel banks (see Figure 34). The 2-year top width for proposed conditions at the BFW-5 location (at station 5+95) is approximately 7.5 feet, matching the BFW measured in the field. See Appendix H for the proposed conditions SRH-2D model results.

Downstream of the proposed structure, the grading options are constrained by utilities, a steep roadway embankment, and proximity to adjacent property. Consequently, the side slopes were increased to a ratio of 1.5:1 (horizontal:vertical) to match the existing slope. There are no other variations in the cross-sectional shape of the proposed channel. Preliminary geotechnical investigations indicate that bank stabilization will be necessary to prevent bank erosion and maintain slope stability at the downstream end of the proposed channel. See Section 4.3.2 for further discussion and Appendix D for preliminary design plans. In later stages of the project, a low-flow channel will be added that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field.

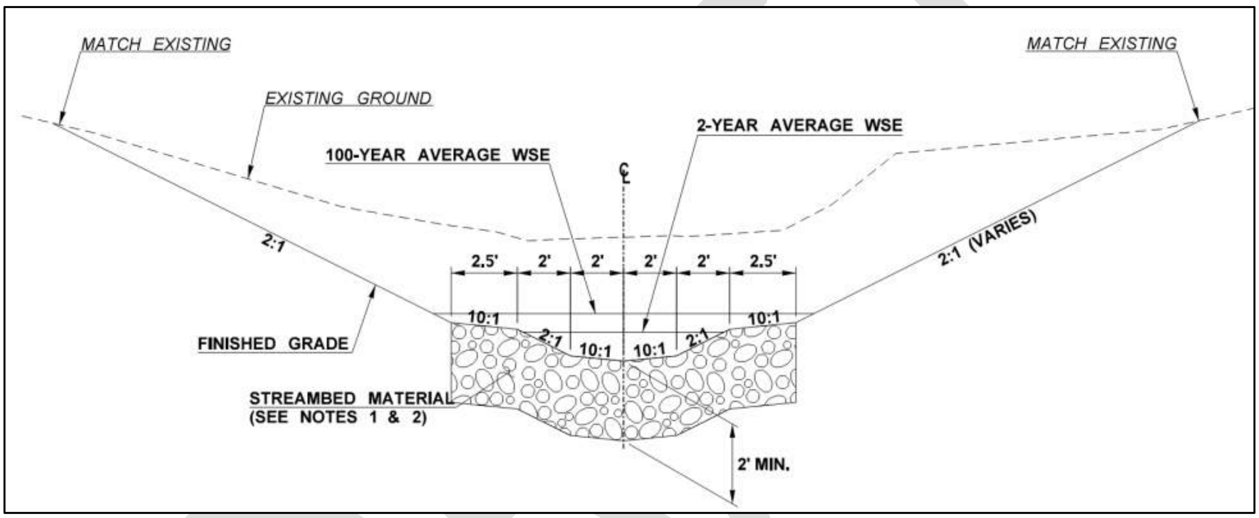

Figure 34: Design cross section

Meander amplitudes are in the range of 13 feet to 20 feet upstream of the SR 308 crossing (see Figure 35). The large meander between station 11+50 and station 12+50 was not included because this meander is forced by the adjacent hillslope. The minimum hydraulic opening has been increased to accommodate for some lateral migration through the structure (see Section 4.2.2).

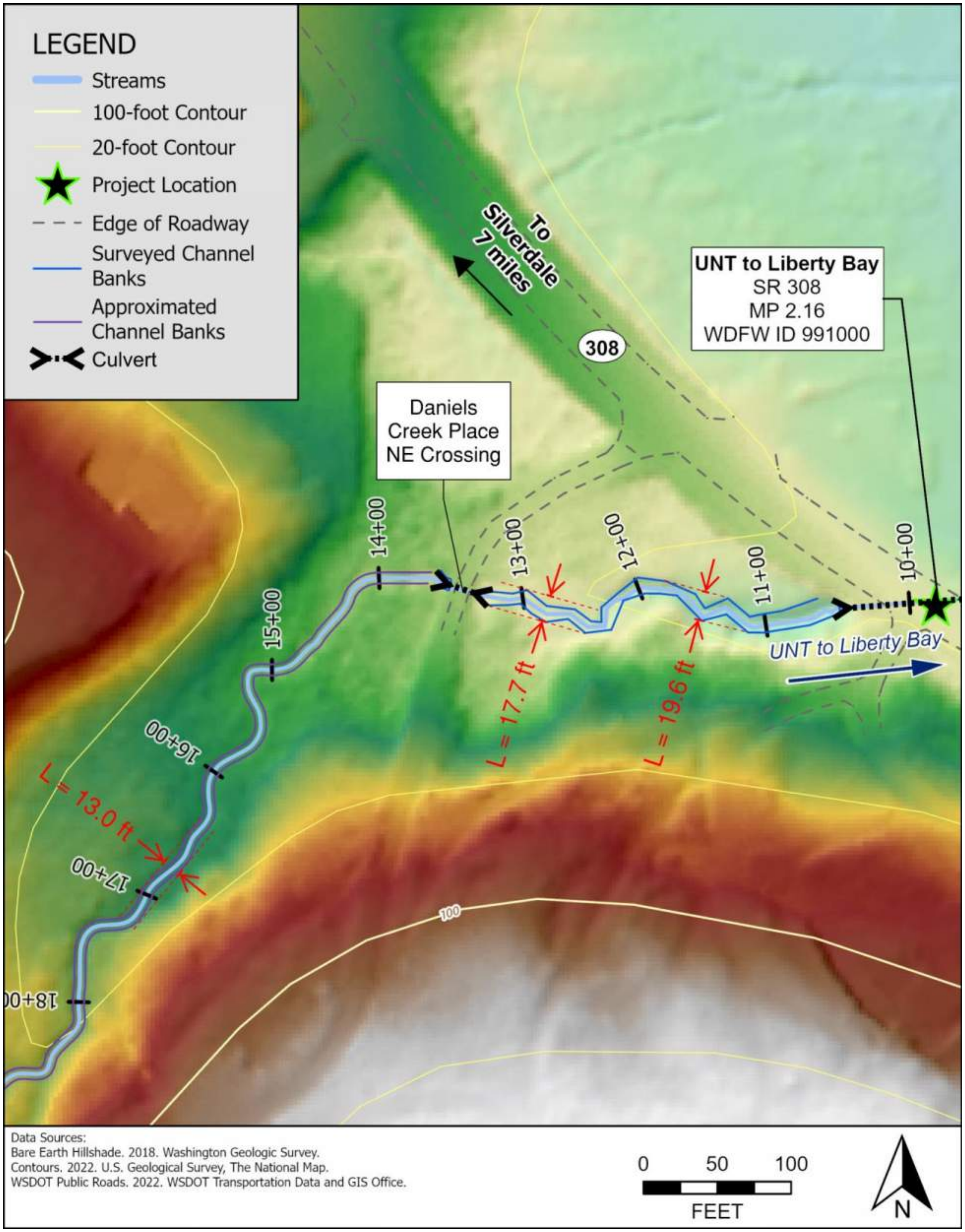

Figure 35: Meander belt width assessment

4.1.2 Channel Alignment

The proposed channel includes a realignment at the upstream end of the existing culvert so that the downstream end of the proposed structure will be directed away from the channel banks adjacent to the downstream property. The co-managers proposed this realignment during the December 17, 2021, site visit. The proposed length of reconstruction is 225 feet, from station 2+25 to station 4+50 (see Figure 36). This realignment will result in a 3-foot loss of stream length compared to the existing alignment. Considering the total length of reconstruction and the habitat gained by creating a channel within the proposed structure, this loss of stream length is negligible.

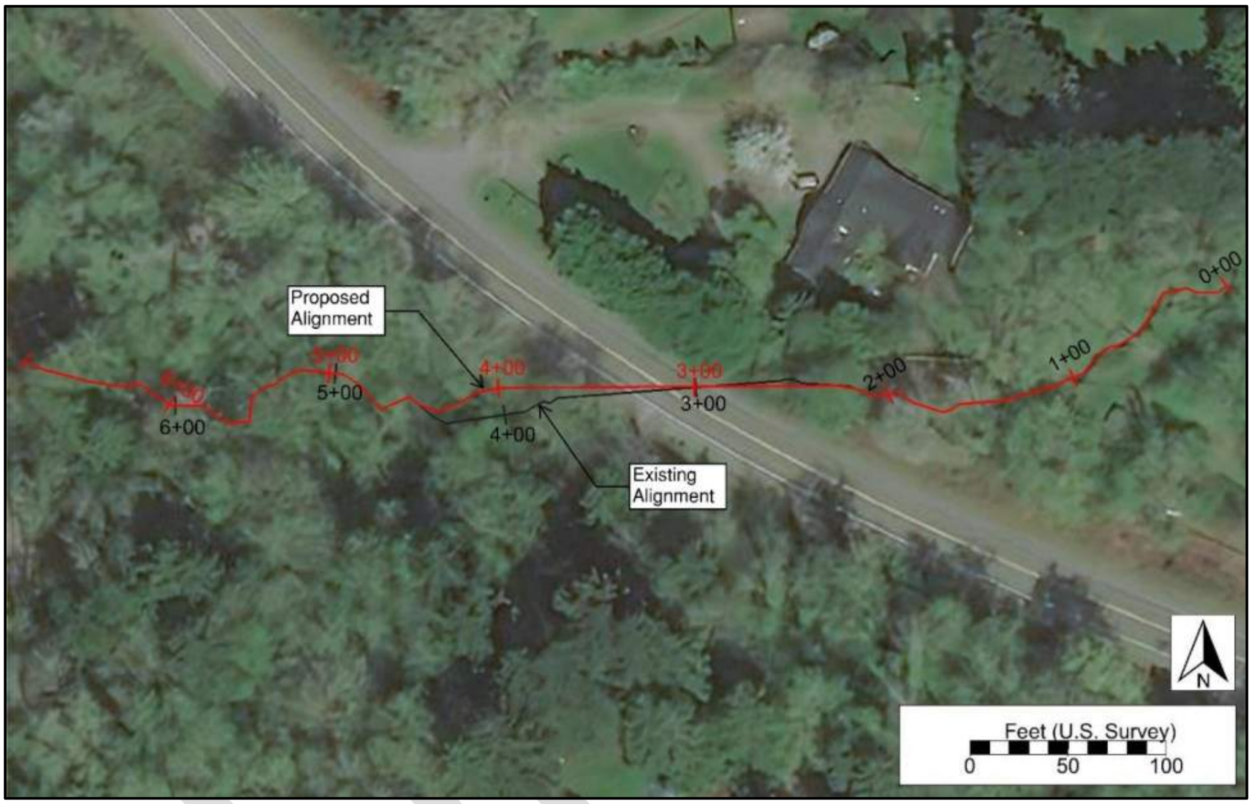

Figure 36: Existing and proposed stream alignments

The proposed alignment will tie into the existing alignment approximately 40 feet downstream of existing culvert outlet and approximately 77 feet upstream of the existing culvert inlet. The proposed realignment will result in a 4-degree increase in skew with respect to the roadway and will be straight for approximately 172 feet, both within the culvert and on both the upstream and the downstream ends of the culvert. This design will align the flow with the structure at the entrance and exits of the proposed structure and minimize potential for lateral migration and scour. The proposed realignment at the upstream end of the culvert also will be beneficial for construction because the steep hillslope along the right bank at the upstream end of the existing culvert would be challenging for construction access and grading options. The proposed realignment will move the upstream end of the proposed structure farther away from this hillslope. The existing channel at the upstream end of the proposed realignment will be filled or reverse graded to drain into the proposed channel and thus minimize potential for erosion or lateral migration at the structure inlet, as well as to prevent fish stranding. The resulting overbank area and remnant channel will also provide additional floodplain capacity and velocity refuge during higher flows. At the upstream and downstream ends of the proposed reconstruction, horizontal curves from 15 feet to 35 feet in radius and 10 feet to 25 feet in length will be used to tie in the proposed alignment to the existing alignment. This proposed design will match the sinuosity observed within the reference reach. See Appendix D for stream plans.

4.1.3 Channel Gradient

The existing culvert was placed at a natural grade break in the channel, at the toe of a hillslope. Since installation of the existing culvert, the downstream channel slope has decreased due to channelization and scour. Consequently, the channel slope differs by approximately 1.5 percent between the reaches upstream and downstream of the crossing (see Figure 29). Section 7-4.1.3 of the WSDOT Hydraulics Manual states that for such a situation it may be necessary to allow for a natural channel regrade, or to design an over-coarsened channel (WSDOT 2022a). The approach for this crossing is to resist potential degradation by designing an over-coarsened channel. See Section 4.3.1 for bed material design.

As stated in Section 2.7.1, the average slope through the reference reach is 3.8 percent. The slope of the proposed channel profile is 3.3 percent, which results in a slope ratio of 1.15; therefore, the proposed channel slope is within 25 percent of the reference reach slope. This proposed slope of 3.3 percent is less than the slope of the reference reach upstream of the existing culvert, but greater than the 2 percent slope downstream of the culvert. This slope is suitable for this project, which is located at the toe of a hillslope, at the inflection point between the valley floor and the upstream ravine (see Figure 2). The proposed channel reconstruction will also remove the vertical drop at the downstream end of the culvert. See Appendix D for the proposed stream profile plans.

Approximately 3 feet of aggradation can be expected at this site when the upstream culvert crossing (WDFW ID 996939) is removed at some future date (see Section 2.7.4). The aggradation is not expected to alter the channel slope significantly. See Section 4.2.3 for discussion on how the proposed design considers additional freeboard to compensate for potential aggradation.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 37 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

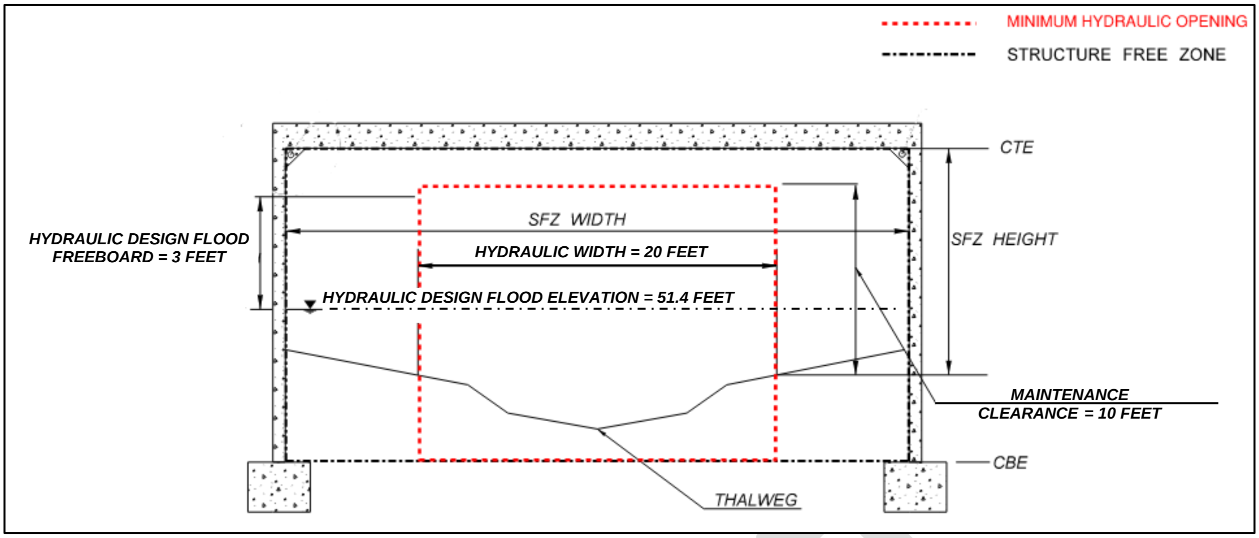

Figure 37: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using WCDG (Barnard et al. 2013) and the WSDOT Hydraulics Manual (WSDOT 2022a). Using the guidance in these two documents, the confined bridge design method was determined to be the most appropriate at this crossing. The confined bridge design method uses the same criteria as stream simulation to determine the minimum hydraulic opening, but is generally required on systems greater than 20 feet (WSDOT 2022a). The stream simulation approach for sizing the minimum hydraulic opening is appropriate because the BFW, FUR, and slope ratio fall within the appropriate ranges. However, the existing stream has meander widths of up to 20 feet (see Section 4.1.1), which necessitates use of the confined bridge design method. The average FUR was determined to be 2.1 (see Section 2.7.2.1) and the BFW is 7.5 feet (see Section 2.7.2 for BFW determination). A suitable reference reach was found such that the slope ratio of the proposed channel is within 25 percent of the existing channel, as discussed in Section 4.1.3. The lowest elevation of the roadway pavement at the crossing is approximately 57.7 feet (at the downstream end of the roadway), which is approximately 10.0 feet above the highest streambed ground elevation within the hydraulic width. Providing adequate freeboard and maintenance clearance for this project will be a unique challenge, as discussed in Section 4.2.3. The length of the proposed crossing is approximately 130 feet, depending upon the structure type (which is yet to be determined, as discussed in Section 4.1.2). The channel is currently laterally stable (see Section 2.7.5) but may migrate if future aggradation occurs (see Sections 2.7.4 and 4.2.3), and the proposed design will accommodate potential vertical instabilities (see Section 7.2). The projected 2080 100-year flows were modeled to ensure that the proposed hydraulic width is suitable to address climate change.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 11 feet was determined to be the minimum starting point. The hydraulic width was increased to 20 feet for the reasons discussed below.

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. For the stream simulation design method, the WSDOT Hydraulics Manual (WSDOT 2022a) recommends determining the span of a proposed structure by using the agreed-upon BFW, with the span being the greater of 1.2 x BFW + 2 feet (WSDOT Hydraulics Manual Equation 7-1) or 1.3 x BFW (WSDOT Hydraulics Manual Equation 7-2). For the UNT to Liberty Bay with the agreed-upon BFW of 7.5 feet, Equation 7-1 results in a minimum hydraulic opening of 11.0 feet, and Equation 7-2 results in a minimum hydraulic opening of 10.0 feet. For this crossing, a minimum hydraulic width of 11 feet was determined to be the minimum starting point.

The WCDG also recommends in some cases to increase the minimum hydraulic opening due to excessive backwater, velocity differences between the crossing and the adjacent undisturbed reach, expected channel migration, or natural sinuosity of the channel, or if the proposed structure is considered a long crossing (Barnard et al. 2013). Long crossings are defined as any crossings where the ratio of the crossing length to the minimum hydraulic opening exceeds 10.

For the proposed project, a hydraulic opening of 11 feet and a proposed length of approximately 130 feet (see Section 4.2.4) result in a length-to-span ratio of approximately 11.8, which is considered a long crossing. This situation warrants consideration of additional hydraulic width to reduce velocities through the structure. The WCDG recommends increasing the minimum hydraulic opening width by 30 percent for long crossings (Barnard et al. 2013). Consequently, hydraulic width was increased by adding 30 percent to the results from Equation 7-1, resulting in a hydraulic opening width of 15 feet and a factor of safety of 2.0 compared to the average BFW of 7.5 feet.

Additional width beyond the 15-foot minimum hydraulic opening to accommodate for lateral migration is recommended. Meander belt widths upstream of the crossing are as great as 20 feet (see Section 4.1.1). Therefore, a 20-foot minimum hydraulic opening is recommended to provide sufficient width for the confined channel to form some natural sinuosity through the structure consistent with the reference reach (see Section 4.1.1). Because the channel is confined, velocity ratios were not assessed. The channel is currently laterally stable (see Section 2.7.5) but may migrate if future aggradation occurs (see Sections 2.7.4 and 4.2.3). Floodplain connectivity, FPW, valley width, long-term vertical stability, existing backwater conditions, floodplain elevations, stream sinuosity, channel complexity features, and continuity of channel processes have also been considered, and do not warrant additional hydraulic width at this crossing.

Based on the factors described above, a minimum hydraulic width of 20 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. To evaluate whether the velocities in the proposed channel necessitate a wider hydraulic opening to accommodate climate change, the velocities from the 100-year flow event were compared to the velocities from the 2080 100-year event. Table 7 compares the velocities of the 100-year and projected 2080 100-year events. The velocities through the structure for both events are generally 1 cfs to 3 cfs greater than the velocities in the channel upstream and downstream of the crossing. The percentage increase in velocities between the 100-year and 2080 100-year flows within the structure is comparable to the percentage increase between those in the channel upstream and downstream. No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

Table 7: Velocity comparison for 20-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
DS 0+40 (A)	5.0	6.9
DS 1+30 (B)	5.4	6.3
DS 2+05 (C)	5.3	5.2
Structure 3+12 (D)	6.6	7.5
US 4+15 (E)	3.8	4.3
US 5+00 (F) – Reference Reach	6.3	7.5
US 5+95 (G)	5.0	5.5

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The WSDOT *Hydraulics Manual* requires 3 feet of freeboard for all structures greater than 20 feet and on all bridge structures unless otherwise approved by HQ Hydraulics (WSDOT 2022a). Long-term aggradation and debris risk were also evaluated at this location. To account for the risk of aggradation risk, 3 feet of freeboard was added, resulting in a minimum required freeboard of 6 feet. More information on the risk for long-term aggradation can be found in Section 2.7.4. There is no recommendation of additional freeboard to address the risk of debris accumulation, which is low (see Section 4.2.3.2).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.4 foot at the upstream structure face for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 include boulders within the structure that may need to be maintained (see Section 4.3.2). Therefore, a maintenance clearance of 10 feet to allow for machinery to access and operate under the structure is required. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

The existing roadway fill height is approximately 11.2 feet and 10.0 feet above the highest streambed ground elevation within the hydraulic width at the upstream and downstream edges of the roadway, respectively (see Appendix D). This fill height is not sufficient to provide the required 10-foot maintenance clearance unless the roadway is raised. During final design, alternatives other than raising the roadway should be considered. These alternatives may include maintenance access hatches within the traveled way, and/or coordination with WSDOT HQ Hydraulics and WSDOT Maintenance to address the need for special maintenance equipment.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	2+49	3+79
Thalweg elevation (ft)	44.5	48.8
Highest streambed ground elevation within hydraulic width (ft)	46.3	50.6
100-year WSE (ft)	46.7	51.0
2080 100-year WSE (ft)	47.2	51.4
Required freeboard (ft)	6.0 [a]	6.0 [a]
Required maintenance clearance (ft)	10.0	10.0
Required minimum low chord, 100-year WSE + freeboard (ft)	52.7	57.0
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	53.2	57.4
Recommended minimum low chord, highest streambed ground elevation within hydraulic width	56.3 [b]	60.6 [b]
Required minimum low chord (ft)	56.3 [b]	60.6 [b]

[a] 3 feet added to accommodate for aggradation

[b] This will require a roadway raise

4.2.3.1 Past Maintenance Records

WSDOT Area 2 – Port Orchard Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

Approximately 3 feet of aggradation can be expected at this site when the upstream culvert crossing (WDFW ID 996939) is removed. See Sections 2.7.4 and 4.2.3 for a discussion of aggradation risk, and see Section 7.2 for a more detailed discussion of long-term vertical channel stability associated with degradation risk. To account for long-term aggradation, 3 feet of freeboard was added to the required minimum of 3 feet of freeboard, for a total of 6 feet of freeboard (see Table 8).

There is low risk for LWM to cause additional freeboard issues at this site. The BFW for this stream is small, and flows are not sufficient to transport LWM. Any treefall occurring adjacent to this stream is likely to remain in place (see Section 2.6.4). Proposed LWM upstream of the crossing will be designed to be stable (see Section 4.3.2). The site is located in a rural area where dense development is unlikely in the near future. Future logging may contribute to increased flows at the crossing, but upstream crossings will prevent LWM from being transported to this crossing.

4.2.4 Hydraulic Length

A minimum hydraulic width of 20 feet is recommended up to a maximum hydraulic length of 130 feet. If the hydraulic length is increased beyond 130 feet, the hydraulic width and vertical clearance will need to be reevaluated. Due to the skew of the proposed alignment, the final length of the structure will be dependent upon the structure type. WSDOT protocol for preliminary design assumes that a bridge width will match the existing pavement width and a culvert will be the approximate length of the existing culvert or roadway fill. Applying this criteria to the project, a culvert may be in the range of 130 feet long, whereas a bridge may be only 60 feet long.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 308 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for the UNT to Liberty Bay at SR 308 MP 2.16.

4.3.1 Bed Material

The development of the proposed streambed mix followed methods recommended in the WCDG (Barnard et al. 2013) for sizing streambed material in culverts and the WSDOT Hydraulics Manual (WSDOT 2022a). The proposed streambed mix design is intended to mimic the average of PC-1 and PC-2 using WSDOT standard streambed mixes (WSDOT 2023). These streambed mixes consist of well-graded, rounded sediment suitable for placement in fish-bearing streams. The mixes include larger sediment classes to promote stability of the mix as well as smaller particle sizes to reduce porosity and subsurface flow during low-flow periods, which would result in less water depth for fish passage. In general, a minimum 30 percent of the total mix should consist of WSDOT streambed sediment (WSDOT Standard Specification 9-03.11(1)) to fill the interstitial spaces between the larger material within the mixes.

Calculations indicate that the existing streambed sediment is highly mobile and, in the absence of adequate sediment supply caused by the restriction at the upstream culvert crossing (WDFW ID 996939), the streambed within the proposed SR 308 crossing may degrade over time. This conclusion is verified by the evidence of channel incision downstream of the existing culvert (see Section 2.6.1 and 2.7.4). Over-coarsened streambed material is considered necessary to achieve a stable configuration at this crossing. To further reduce the risks of vertical degradation, the proposed design includes channel complexity features to retain sediment within the proposed channel. Boulder clusters composed of stable material will be installed through the structure, and LWM will be installed outside of the structure.

The proposed overcoarsened streambed design mix is composed of 30 percent Streambed Sediment (WSDOT Standard Specification 9-03.11(1)), 50 percent 10-inch cobbles (WSDOT

Standard Specification 9-03.11(2)), and 20 percent 12-inch cobbles (WSDOT Standard Specification 9-03.11(2)). The D_{50} for the proposed streambed gradation (2.4 inches) is more than 20 percent greater than the D_{50} within the reference reach (0.8 inches). The D_{50} within the reference reach was determined using the Wolman Pebble Count method (see Section 2.7.3). The D_{100} of the overcoarsened mix is 12.0 inches compared to the existing D_{100} of 3.5 inches.

The modified Shields equation was used to determine the stability of the proposed streambed sediment mix for the modeled peak flows. This equation is suitable for assessing particle stability in channels with gradients less than 5 percent, with particle sizes ranging from 2.5 inches to 10 inches, and with high relative submergence (i.e., where the majority of particles within the stream are submerged) (USDA 2008). The UNT to Liberty Bay satisfies most of these criteria, with the exception that some of the particles are outside the range of particle sizes recommended for use of the modified Shields equation. However, due to the lack of more suitable design equations, the modified Shields equation is often used in similar scenarios. The key parameter input to this equation is shear stress of the flow acting on the channel bed. The average shear stress across the channel within the proposed structure was determined from the hydraulic modeling (see Section 5.4 for proposed conditions model results). The over-coarsened mix is designed so that the D_{84} is stable at the 2-year event. All sediment from the D_{16} to the D_{100} of the overcoarsened mix is mobile at all events greater than the 2-year event.

Preliminary scour calculations predict approximately 5.1 feet of scour for the scour design event (see Section 7.5). The preliminary design for UNT to Liberty Bay specifies a total of 5 feet of streambed material throughout the entire reconstructed channel (see Appendix D for proposed stream plans). The proposed streambed sediment will provide suitable spawning gravel for salmonids and other anadromous fish.

Table 9 includes the proposed sediment gradation for the streambed sediment. See Appendix C for streambed material sizing calculations. A stream simulation bed material mix is included in Appendix C for reference purposes.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Overcoarsened sediment diameter (in)
$\mathbf{D_{16}}$	0.2	0.6
$\mathbf{D_{50}}$	0.8	2.4
$\mathbf{D_{84}}$	1.5	8.1
$\mathbf{D_{95}}$	2.1	9.8
$\mathbf{D_{100}}$	3.5	12.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Liberty Bay at SR 308 MP 2.16.

4.3.2.1 Design Concept

Channel complexity features for the SR 308 crossing are designed to provide habitat and allow for natural stream processes. The channel complexity features for this crossing include LWM in restored open-channel areas and boulder clusters within the proposed structure. Additionally, steps and pools mimicking characteristics within the reference reach should be considered during the final design phase. These channel-forming features are expected to prevent plane-bed morphology and entrainment against the structure walls, and instead to maintain a pool-riffle morphology throughout the proposed crossing. The boulder clusters will also increase roughness and reduce velocities through the proposed structure. Mobile woody material is not proposed for this crossing at this time.

Meander bars are not proposed for this crossing. Instead, boulder clusters are spaced at approximate 25-foot intervals through the proposed crossing. This spacing will encourage low flow sinuosity through the proposed channel at an amplitude comparable to the reference reach. In order to prevent plane-bed morphology from developing if post-construction aggradation occurs the boulder clusters will be stacked high enough that they are exposed even if 3.0 feet of aggradation occurs (see Sections 2.7.4 and 4.2.3). The boulder clusters should be composed of type-two and type-three boulders as defined in the WSDOT Standard Specifications (WSDOT 2023). The downstream end of each boulder cluster should include a tail composed of material with a D_{84} that is stable during the 100-year event, and the mix should include a minimum of 30 percent WSDOT streambed sediment (WSDOT Standard Specification 9-03.11(1)). The tail on the downstream end of each boulder cluster should resemble the configuration and provide similar functions as a meander bar tail (WSDOT 2022b). The boulder clusters resemble meander bars in form and function, but the WSDOT meander bar design guidelines result in a very coarse meander bar tail on overcoarsened streams because it is required that the D_{50} of the meander bar tail shall be greater than the D_{84} of the proposed streambed. Applying the meander bar design criteria to this crossing results in a meander bar tail that is coarser than the meander bar head. Therefore, boulder clusters are proposed rather than meander bars. A low-flow channel will be constructed between the boulder clusters to facilitate fish passage. See Figure 38 for a conceptual cross section of the boulder clusters.

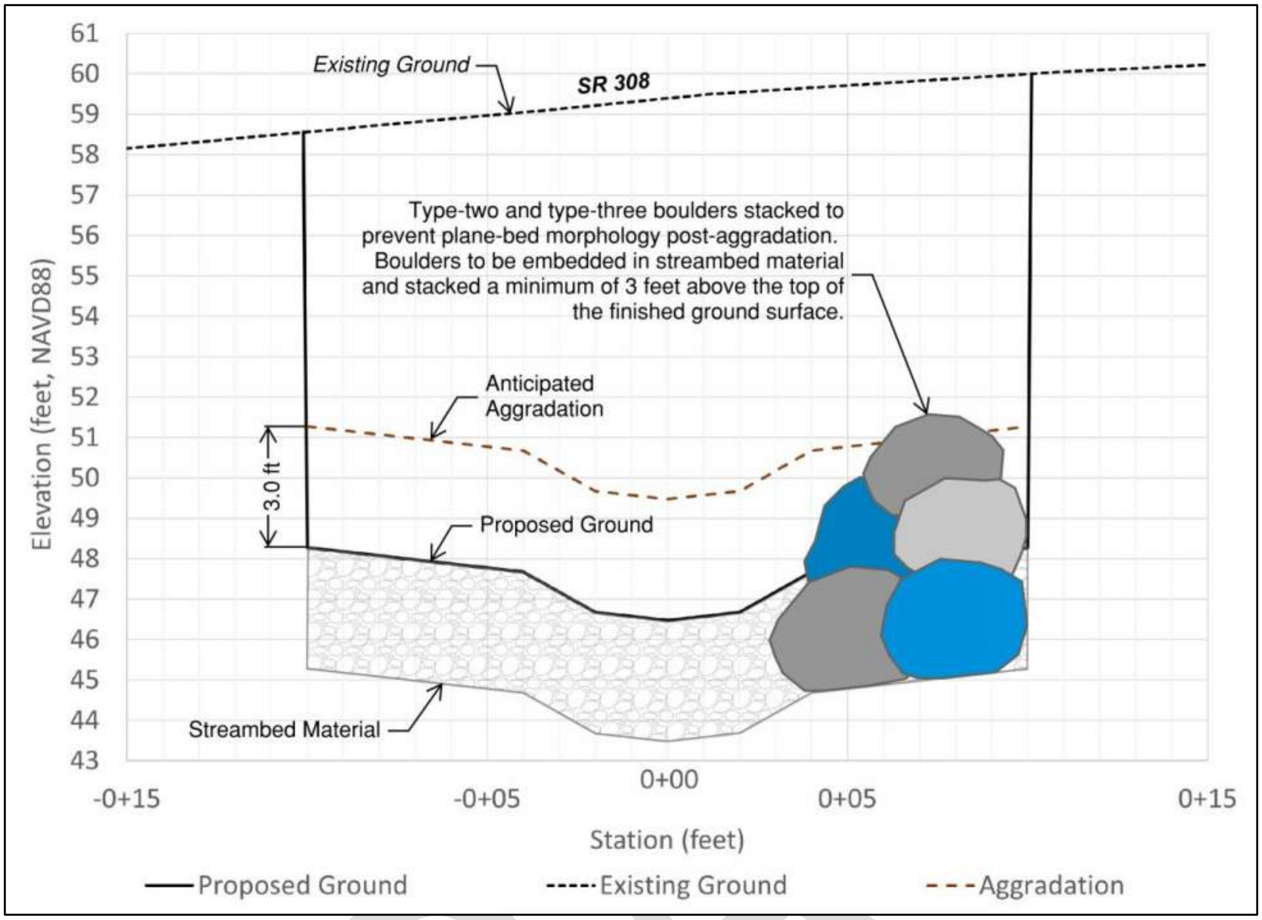

Figure 38. Boulder Cluster Cross Section

The design for this crossing proposes a constructed channel that mimics the existing reference reach to provide fish passage. Because of the multiple steps and pools documented within the reference reach (see Sections 2.6.1 and 2.7.1), the proposed channel is designed to include aspects of step-pool morphology. Steps and pools dissipate energy and retain sediment, both of which promote streambed stability. Steps and pools also provide a variety of other ecosystem functions, including the formation of scour pools and localized sediment gradations due to sediment sorting. Scour pools and large boulders within riffles also provide resting areas for fish (USDA 2008).

Step-pool design guidance for Western Washington is currently under development, and WSDOT is making efforts to utilize the best available science to design fish-passable structures on steep-gradient, coarse-bedded streams. As suggested in the document *Providing Aquatic Organism Passage in Vertically Unstable Streams*, the design of steps for this project is based on the characteristics measured within the reference reach, not necessarily on rigid parameters such as allowable step height (Castro and Beavers 2016). This guidance aligns with the Stream Simulation design methodology (USDA 2008). The concept of stream simulation rests on the assumption that if fish can utilize habitat within the reference reach, then it is reasonable to expect a design that simulates the reference reach will provide adequate fish passage for the species and life stages expected to utilize the crossing. A variety of depths, velocities, and substrate throughout the crossing will provide the maximum amount of high-quality habitat, as opposed to a uniform cross section with identical steps that adheres to rigid design guidelines, which has often been the conventional hydraulic engineering approach when designing step-pool systems (Castro and Beavers 2016). However, the steps for this crossing should not exceed the 0.8-foot maximum height recommended in the WCDG (Barnard et al. 2013).

The proposed steps should be composed of woody material designed to be immobile. See Figure 41 and Figure 42 for a conceptual layout of the woody material which will be used to create steps through the proposed crossing. Because there were no boulders observed within the channel or overbank areas during the site visits (see Section 2.7.3), it is not necessarily recommended to incorporate boulders into the steps. However, boulders may be incorporated into the steps if they are required in order to achieve stability of the wood used in the steps. Although the existing channel was devoid of LWM, the proposed design may also recommend LWM to achieve stability and reduce the risk of debris accumulation and associated freeboard issues. Some of the steps may be composed of angled logs within the channel that effectively constrict the flow. The logs which comprise the steps need not span the channel in all cases; a single log may be sufficient to cause the variations in velocity and depths that provide the functions of a step. The reference reach exhibits examples of steps such as this (see Figure 39), as well as chutes where the flow is restricted on either side of the channel (see Figure 40). The latter scenario may be emulated by two logs angled up against both the left and right banks, and intersecting in the center of the channel, perhaps embedded within the streambed. The log steps should be constructed under the supervision of the design engineer, and it is recommended that the logs be placed so that the low point in the step is offset between successive steps and therefore the thalweg meanders within the middle third of the channel, mimicking a natural system. Small woody material (SWM) will be incorporated into the streambed material on either side of the low-flow channel, upstream of each step.

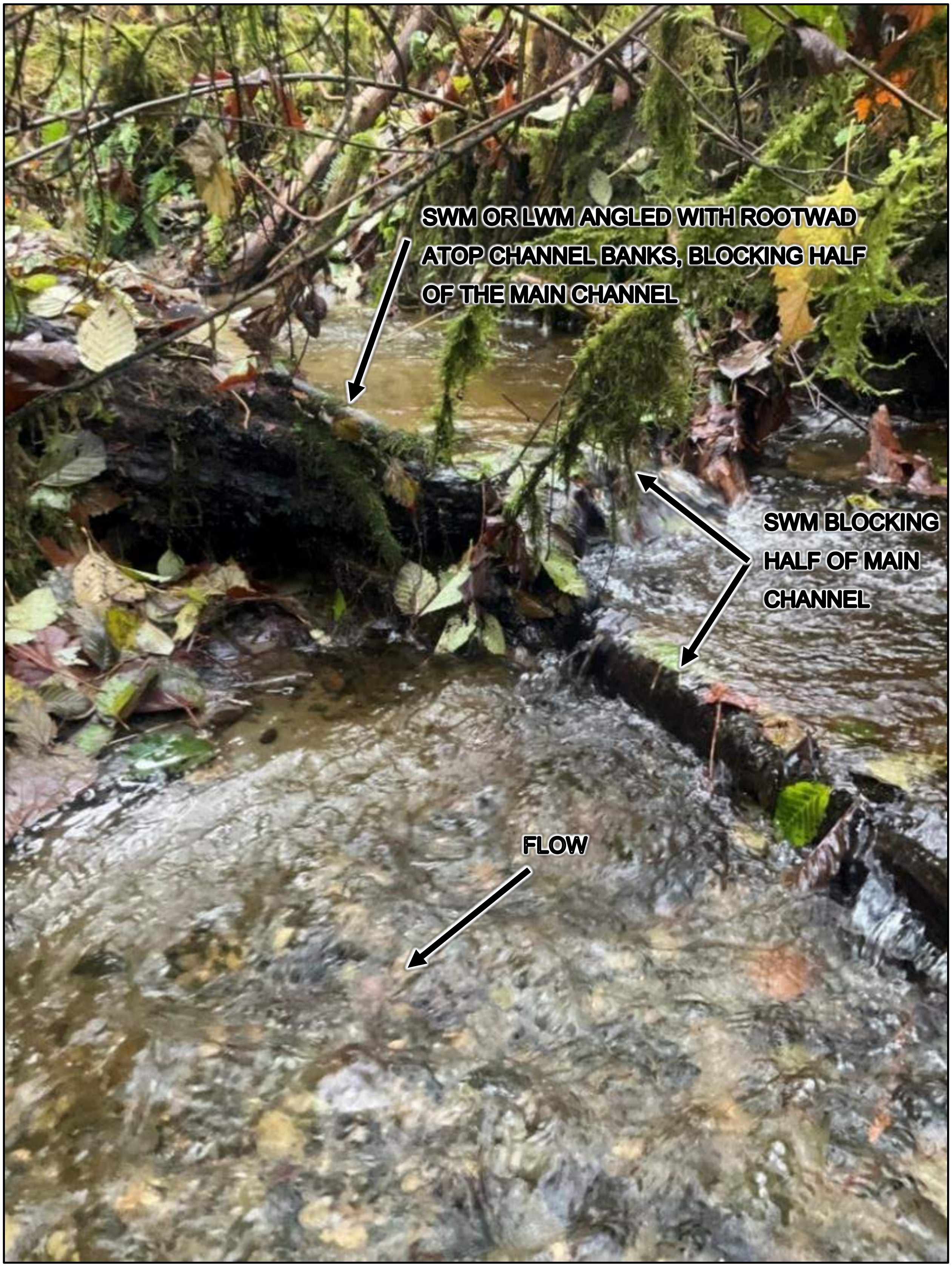

Figure 39: Wood-forced step near downstream end of reference reach (Sta. 4+50)

Figure 40: Wood-forced step near upstream end of reference reach (Sta. 5+25)

The channel complexity features proposed for this crossing also include LWM in restored open-channel areas. LWM consists of logs larger than 6 feet in length and greater than 6 inches in diameter at breast height (DBH), often with rootwads attached. LWM can influence channel morphology, creating beneficial habitat, such as pools, back eddies, side channels, and sinuosity. LWM also helps to retain spawning gravel; provide refuge from predators, high velocities, and adverse thermal conditions; and provides a food source for insects, which in turn provide nourishment to fish (Fox and Bolton 2007). In addition, LWM can increase the stability of newly constructed channels (Castro and Beavers 2016).

The suggested targets in “A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State” (Fox and Bolton 2007) provide the basis for determining the amount of wood placed within the constructed channel. WSDOT has developed a spreadsheet based upon this research that calculates targeted wood metrics for the proposed channel design. This calculation depends upon the total length of reconstructed channel and the BFW of the stream channel. The total length of the channel in this calculation includes the length of the channel through the structure, but WSDOT prefers not to place LWM inside the structure. Consequently, the volume targets for wood on fish passage projects are frequently not met, specifically when the structure length is large in comparison to the total length of reconstruction. The proposed length of channel reconstruction at this site is 225 feet, from station 2+25 to station 4+50. Based on the total length of reconstruction and a BFW of 7.5 feet, the WSDOT log metrics calculation spreadsheet specifies a target of 8 key pieces, 26 total pieces of large wood, and 88.8 cubic yards of wood volume (see Appendix F for the large woody material calculations).

Given that the total length of channel reconstruction is 225 feet and assuming a culvert is selected as the proposed structure, the proposed channel will consist of approximately 95 feet of open channel and 130 feet of channel inside the proposed structure. If a bridge is the selected structure, the structure will need to be only approximately 60 feet long, so additional LWM can be placed within the proposed channel. Figure 41 shows the conceptual wood layout for the culvert configuration. The number of key pieces provided in this configuration is 8 pieces (meets the target), and the total number of large woody material pieces is 26 (meets the target). The total wood volume provided is 25.9 cubic yards, which is approximately 29 percent of the target volume. The addition of buried wood and wood placement outside the limits of grading should be considered during the FHD phase to increase the total volume of wood.

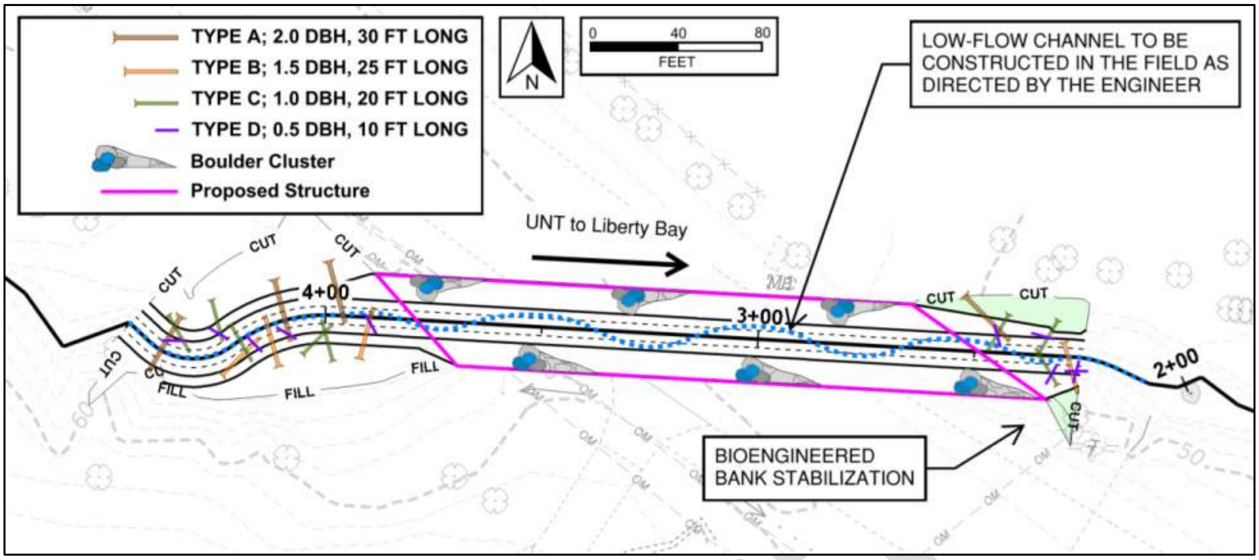

Figure 41: Conceptual layout of habitat complexity – culvert configuration

Figure 42 shows the conceptual wood layout for the bridge configuration. The number of key pieces provided in this configuration is 16 pieces (exceeds target), and the total number of LWM pieces is 52 (exceeds target). The total wood volume provided is 49.6 cubic yards, which is approximately 56 percent of the target. The addition of buried wood and wood placement outside the limits of grading should be considered during the FHD phase to increase the total volume of wood.

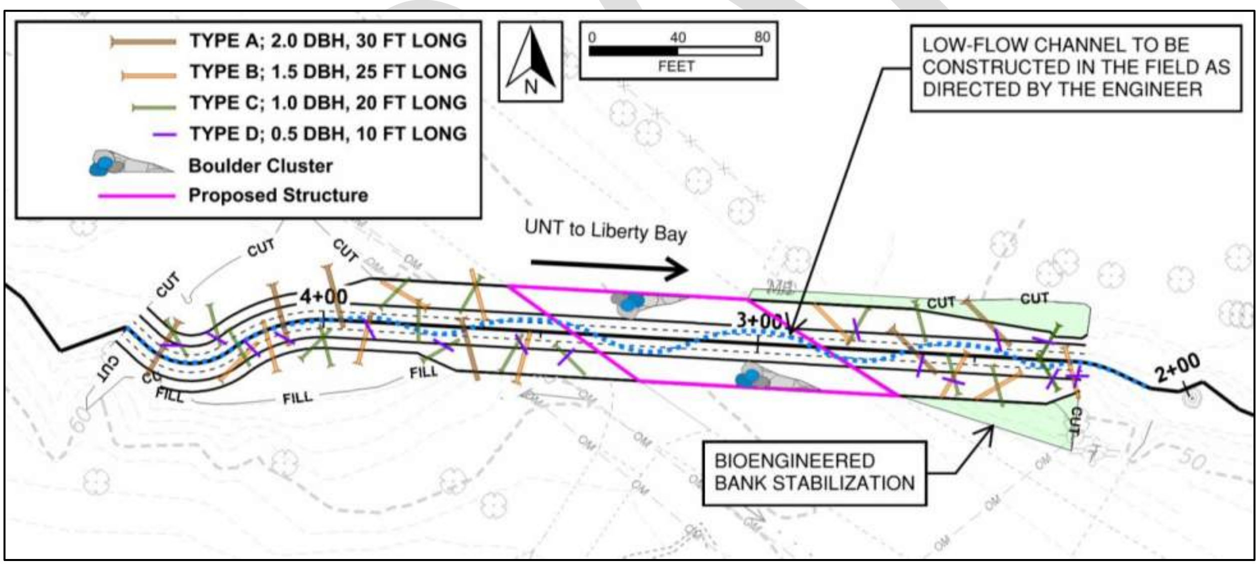

Figure 42: Conceptual layout of habitat complexity – bridge configuration

WSDOT requires that special consideration should be given to LWM within 50 feet of the proposed structure. The peak flows for this watershed are likely insufficient to mobilize the larger pieces of wood but may be able to mobilize the Type D pieces, which are 10 feet long and 6 inches in DBH. Anchoring is anticipated to provide stability for these Type D pieces of wood, until stability calculations are completed that indicate anchoring is not needed. The Final Hydraulic Design Report will include stability calculations.

Most of the large wood will be placed in the upstream channel. Due to the confined nature of the downstream channel, side-slopes will be relatively steep and may need to be stabilized, preferably using bioengineering techniques (riparian plantings, willow stakes, jute mats, coir logs, etc.). Additional measures may be required to maintain stability, pending geotechnical investigation. To maintain conveyance capacity and prevent scour potential in the downstream channel, the design minimizes the amount of LWM in this reach. Partial embedment of the large wood into the channel banks for stability may not be feasible at this location due to the proximity of adjacent private property, including landscaping features such as large hedges and trees with root zones that may be close to the existing channel banks. Large wood placement in the downstream channel shall ensure that bank erosion does not become an issue post-construction.

Some of the logs within the channel should be angled so that part of the log rests on the banks and the other end is embedded within the streambed material. In addition to forcing steps and pools, this configuration will ensure that the logs remain engaged with the flow if post-construction aggradation occurs (see Section 2.7.4 and 4.2.3). Some of the logs may also span the channel, allowing for future recruitment of SWM and engagement with the low-flow channel in the post-aggradation conditions.

A conceptual restoration plan (CRP) will be added at a future draft stage of the PHD.

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 308, UNT to Liberty Bay crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for the UNT to Liberty Bay using the SRH-2D models: (1) existing conditions with the 30-inch-diameter culvert and (2) proposed conditions with the proposed 20-foot minimum hydraulic opening. Section 5.2 discusses the results from the existing conditions model, and Section 5.4 discusses the results from the proposed conditions model. Appendix H provides graphic representations of the results for both scenarios.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model was obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT during December 2021. The survey data were supplemented with light detection and ranging (LiDAR) data (USGS 2018). All survey and LiDAR information is referenced against the NAVD88. The existing 30-inch-diameter culvert crossing at SR 308 was modelled using the HY-8 software package, which is integrated into the SMS:SRH2D program. See Section 5.1.4 for further discussion.

Topographic surface development for proposed conditions site geometry was performed by DEA with the use of InRoads v8i. The proposed horizontal alignment, vertical profile, and cross-sections shown in Appendix D are the basis for the proposed channel grading. The surface for the proposed hydraulic opening includes vertical walls at the edge of the floodplain benches within the proposed structure. Section 4.1 provides further detail regarding the proposed channel grading. The proposed conditions channel grading was imported to SMS:SRH2D and merged with the LiDAR and survey data to create a single merged surface.

Neither the existing conditions survey nor the proposed grading included LWM or other habitat features. Instead, these features were represented with changes to the roughness, as explained in Section 5.1.3.

5.1.2 Model Extent and Computational Mesh

The hydraulic model extends from approximately 250 feet upstream of the existing culvert inlet to approximately 400 feet downstream of the existing culvert outlet. The upstream limit of the model is directly downstream of the culvert crossing at Daniels Creek Place NE (WDFW ID 996939, see Figure 7). The downstream limit of the model is approximately 120 feet upstream from a 2-foot-diameter culvert crossing at Virginia Loop Road (WDFW ID 996938). Virginia Loop

Road has a relatively small roadway prism, and the backwater from this downstream culvert is not sufficient to affect results at the SR 308 culvert crossing. The mesh domains for the overbank areas extend to high points on either side of the channel, so that the higher flows do not contact the mesh boundary and affect model results.

The total mesh area encompasses 4.3 acres. The existing conditions model consists of 13,799 elements, and the proposed conditions model consists of 17,828 elements. Both existing and proposed conditions meshes utilize quadrilateral elements in the channel and triangular elements over the remaining surface area. The meshes have an approximate vertex spacing of 3 feet to 4 feet along the channel banks and an approximate 14-foot vertex spacing near the outer domain limits. Vertex spacing was tightened to 2 feet for an increased level of detail in the vicinity of the existing and proposed crossings. Holes in the mesh are used to represent the vertical walls for the proposed structure. Another hole in the mesh is used to represent a house located on the downstream end of the site. Figure 43 and Figure 44 show the existing and proposed conditions meshes, respectively.

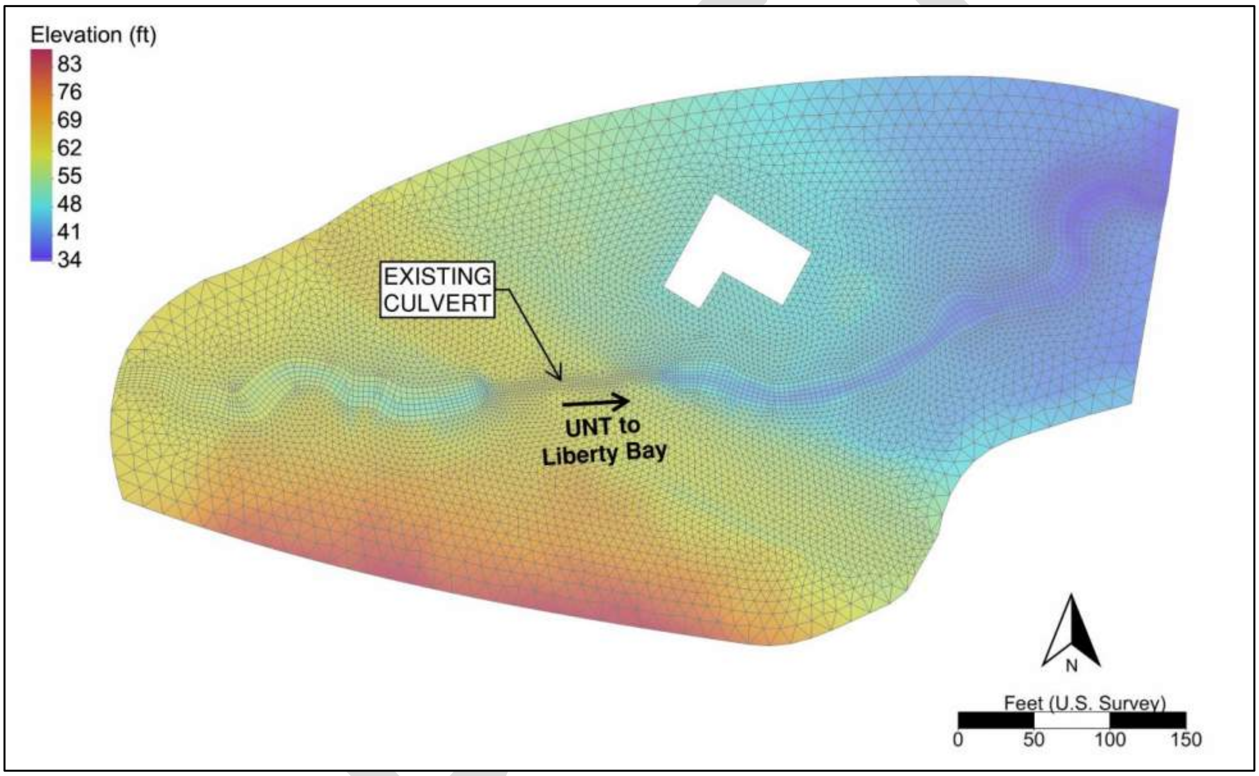

Figure 43: Existing-conditions computational mesh with underlying terrain

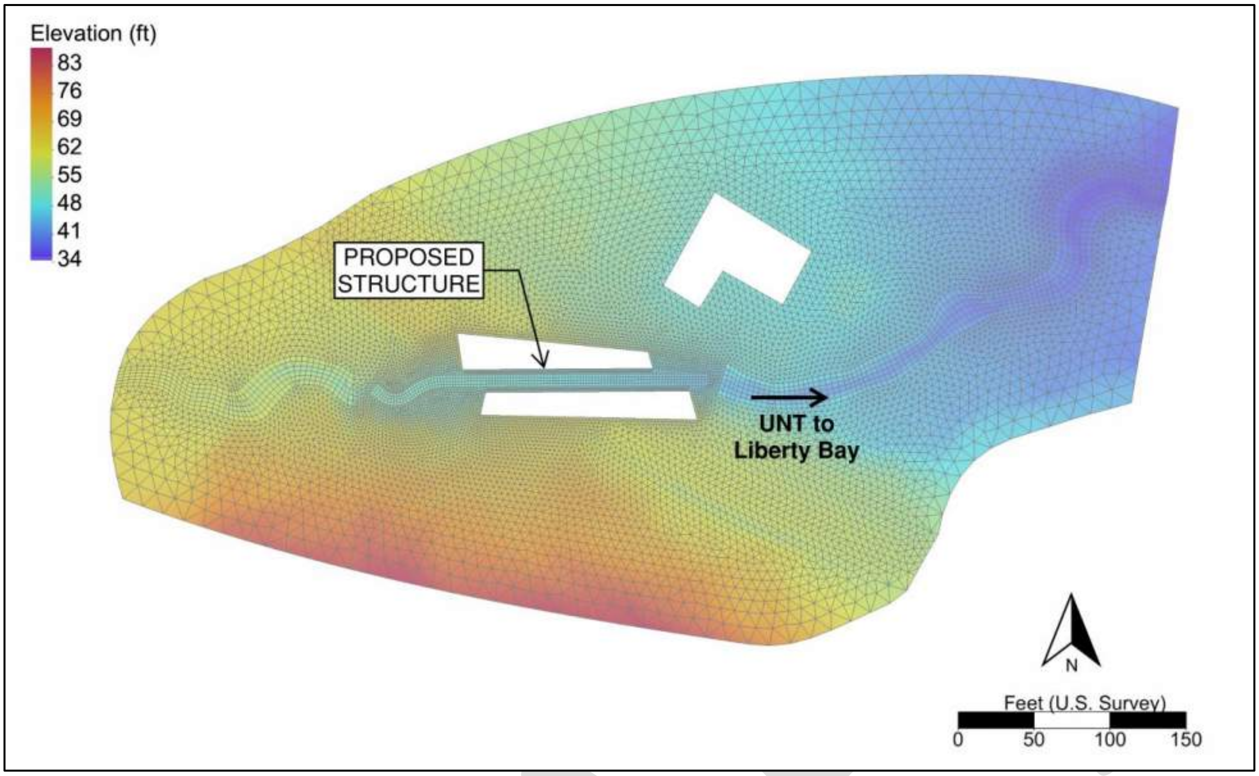

Figure 44: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Roughness values were selected based on a comparison of the categories listed in the WSDOT Hydraulics Manual, Appendix A4 and visual observations from site visits. Table 10 lists the values selected for both the existing conditions and the proposed conditions. Existing and proposed conditions roughness coverages are the same except within the vicinity of the proposed channel. The proposed channel will include LWM, which will drastically increase the roughness compared to existing conditions. The channel within the proposed structure will not contain any LWM, but coarsened streambed material and boulder clusters will be included to increase roughness and reduce velocities through the proposed structure. Consequently, roughness within the culvert has been increased by a Manning's n coefficient value of n=0.005 for proposed conditions, an increase of approximately 13 percent from the existing channel roughness. Figure 45 and Figure 46 show the roughness coverages for existing conditions and proposed conditions, respectively.

Table 10: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Asphalt	0.02
Existing channel	0.04
Overbank (heavy vegetation)	0.07
Overbank (light vegetation)	0.045
New channel (outside structure)	0.08
New channel (inside structure)	0.045

Figure 45: Spatial distribution of existing-conditions roughness values in SRH-2D model

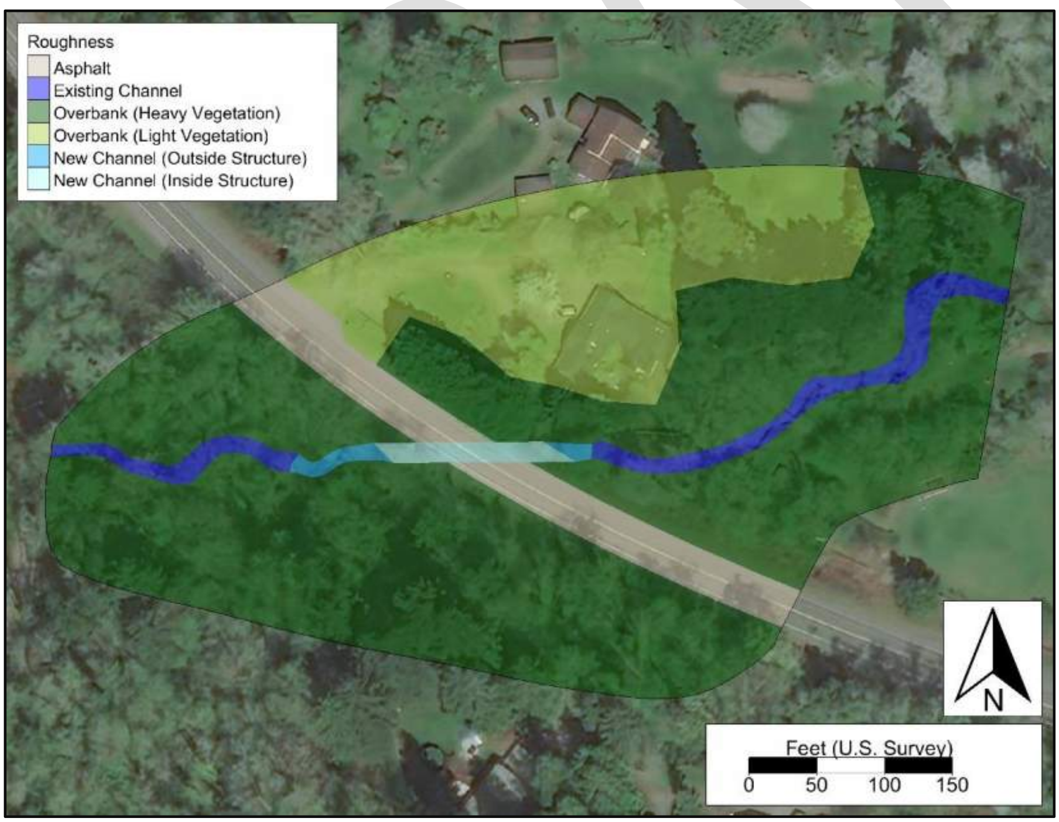

Figure 46: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

The boundary conditions for both existing and proposed conditions include an inflow boundary condition at the upstream end of the model domain and a constant WSE boundary at the downstream end of the model domain.

The inflow boundary was set as a constant inflow (steady flow), with a flow rate corresponding to the peak flows for the various recurrence intervals modeled. Table 11 shows the modeled peak flows for the upstream boundary conditions. See Section 3 for the determination of peak flows. The model designated the inflow boundary condition as subcritical to match the expected flow regimes at this location.

Table 11: Upstream boundary condition values

Recurrence interval	Discharge (cfs)
2-year	25.0
100-year	84.6
500-year	160
Projected 2080 100-year	135

The downstream boundary conditions are specified as a constant WSE that corresponds to the normal depth for each of the simulated peak flows (see Table 12). The WSE were calculated with the SMS Channel Calculator tool, using the peak flows in Table 11 and the parameters in Table 13. Figure 47 plots the normal depth rating curve for the downstream boundary condition. The outflow boundary condition is sufficiently far from the SR 308 crossing that small differences in the WSE at the boundary do not influence the hydraulic results at the project site.

Table 12: Downstream boundary condition values

Recurrence interval	Elevation (feet)
2-year	35.4
100-year	36.1
500-year	36.8
Projected 2080 100-year	36.6

Table 13: Summary of parameters for downstream boundary conditions

Parameter	Value
Energy slope (%)	2.75
Roughness(Manning's n)	0.04

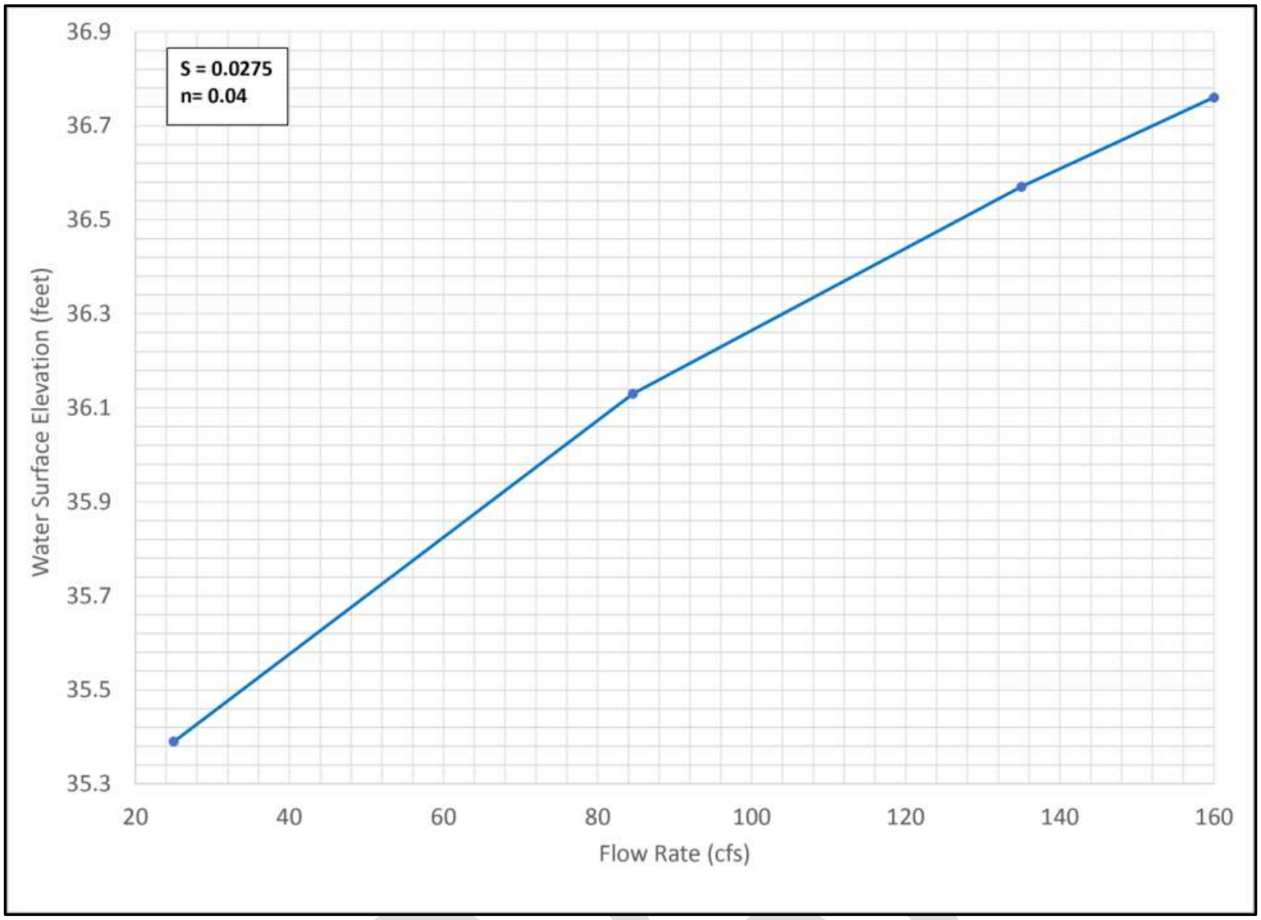

Figure 47. Downstream outflow boundary condition normal depth rating curve

Modeling of the existing 30-inch-diameter culvert crossing at SR 308 required additional boundary conditions. Circular culverts are modeled within SMS by adding boundary conditions at the upstream and downstream ends of the culvert. This boundary condition allows SMS to interface with the Federal Highway Administration (FHWA) HY-8 culvert analysis software (FHWA 2019) for calculating the hydraulics through the existing culvert. Information from the WSDOT survey and the DEA site visit in November 2021 provided the culvert characteristics used in the HY-8 model (see Figure 48). Figure 49 shows the boundary conditions for the existing conditions model.

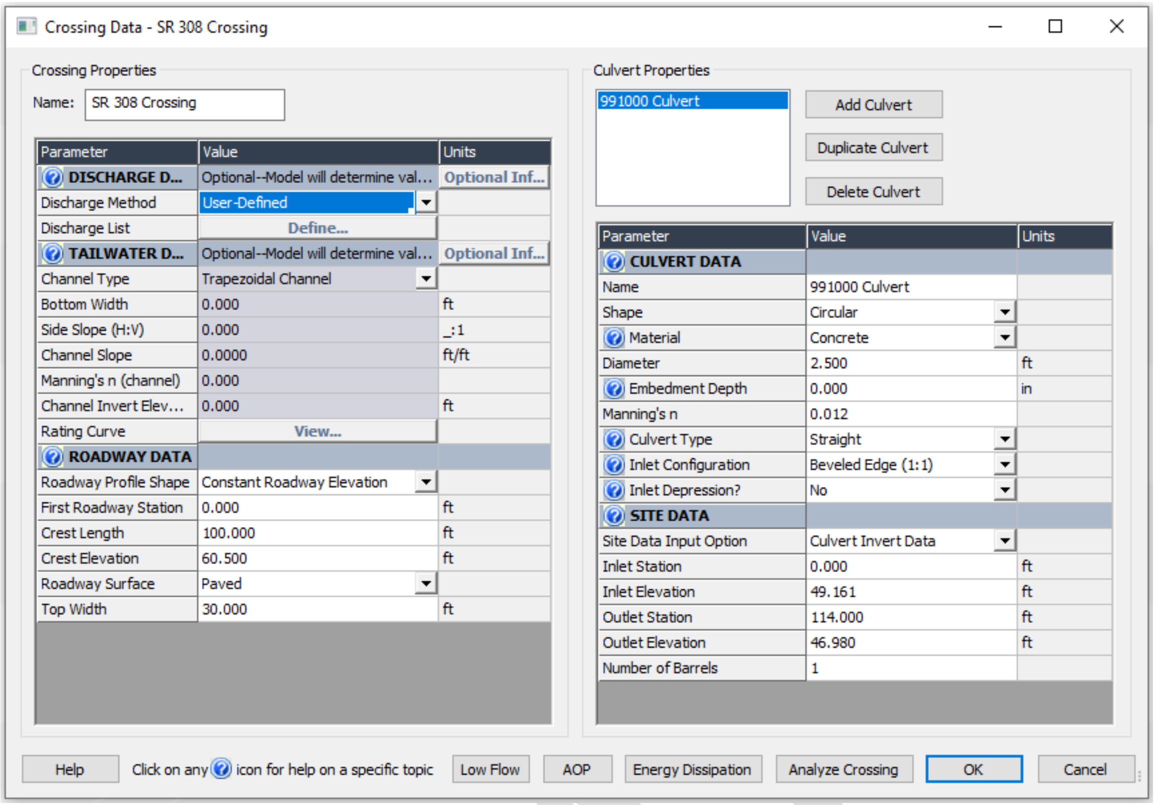

Figure 48: HY-8 culvert parameters

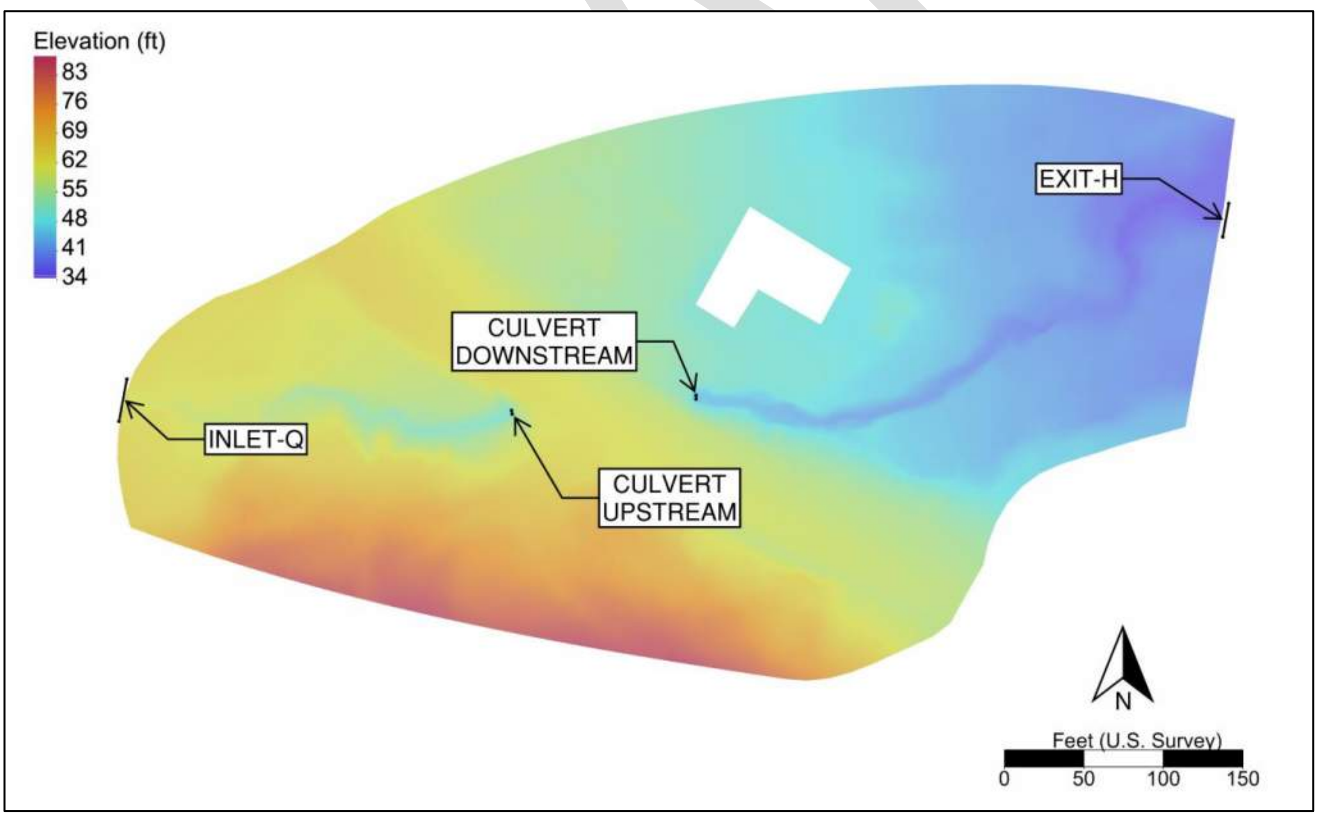

Figure 49: Existing-conditions boundary conditions

The existing culvert was removed in the proposed conditions model. The proposed conditions model includes no-slip wall boundaries along the inside of the holes in the mesh, which were used to represent the vertical walls of the proposed structure (see Figure 50). Pressure flow boundary conditions were not required, because the project will satisfy the freeboard requirements.

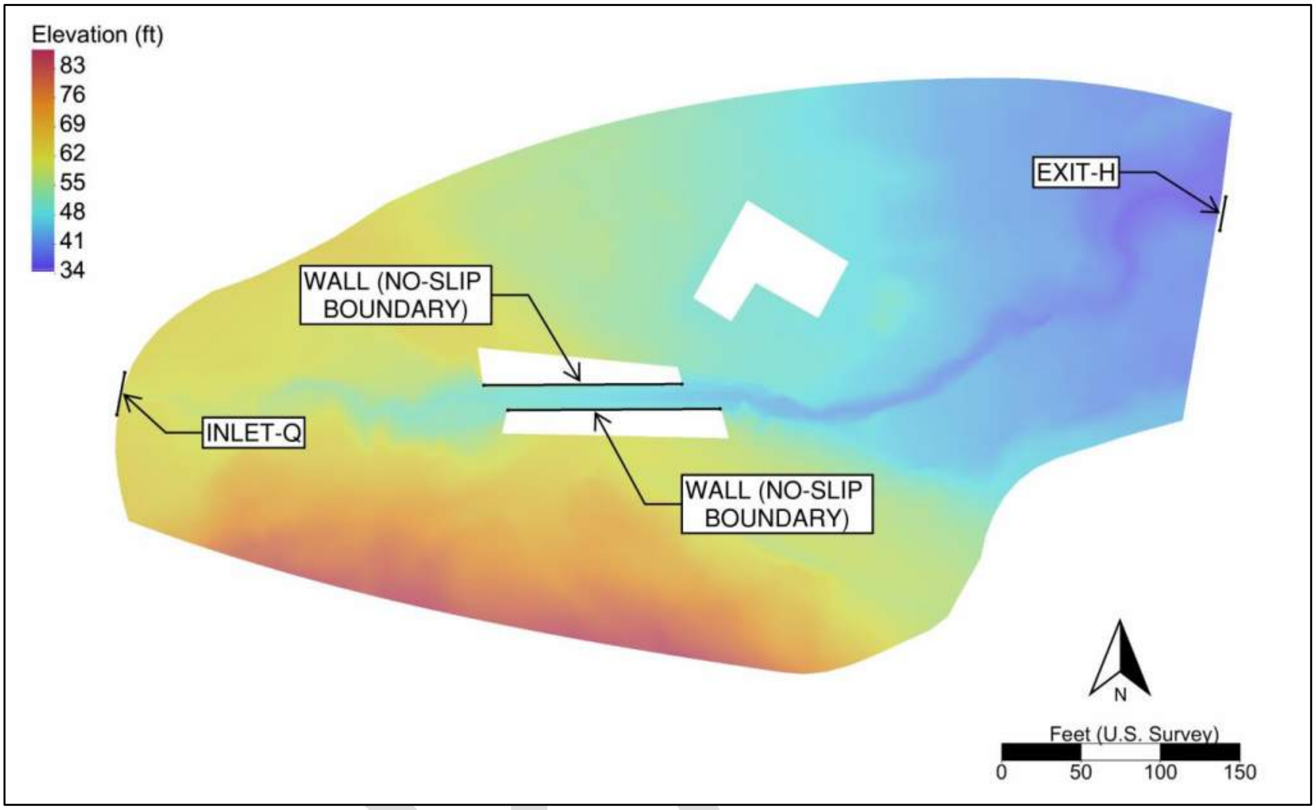

Figure 50: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

The existing and proposed models were run at steady state using 0.2-second time steps until there was no fluctuation in discharge or WSE upstream or downstream of the crossing. The existing simulations ran for 5 hours of simulation time but typically achieved steady state conditions in 4 hours or less. The proposed model ran for 3 hours of simulation time but typically achieved steady state conditions in 30 minutes or less. See Appendix I for plots of model continuity (monitor line) and stability (monitor point). Both existing and proposed simulations were set to dry initial conditions. Turbulence parameters were maintained at the default values.

5.1.6 Model Assumptions and Limitations

Industry-accepted best practices for modeling HY-8 culverts includes editing mesh elevations at the HY-8 boundary condition. More specifically, when the mesh elements are above the invert elevations of the culvert, editing the mesh elevations to lie below the culvert invert is necessary so that flow is not obstructed at the interface between HY-8 and SRH-2D. This approach does not accurately represent real world conditions but is necessary to ensure the model is stable. This project also has a vertical drop at the outlet of the culvert. Although both HY-8 and SRH-2D are capable of modeling vertical drops, a vertical drop in the mesh directly downstream of the HY-8 boundary condition results in excessively high velocities. To achieve more realistic model results, the downstream HY-8 boundary condition was placed downstream of the vertical drop in the mesh, effectively removing the vertical drop from the model.

5.2 Existing Conditions

Model results for the existing conditions hydraulic model were extracted using observation arcs in SMS:SRH-2D. Three cross sections were placed at locations that represent typical downstream conditions, and another three were placed at locations that represent typical upstream conditions. Figure 51 shows the locations of the cross sections where the model data was extracted. Cross sections E and F are located within the reference reach. The results extracted from the hydraulic model were processed using an Excel spreadsheet to determine average or maximum values within the main channel and the overbank areas for each cross section. The main channel extents were determined from the 2-year flood extents, which approximately match the bankfull channel. See Table 14 for the WSE, velocity, depth, and shear stress from the existing conditions SRH-2D model for the 2-year, 100-year, 500-year, and projected 2080 100-year peak flows.

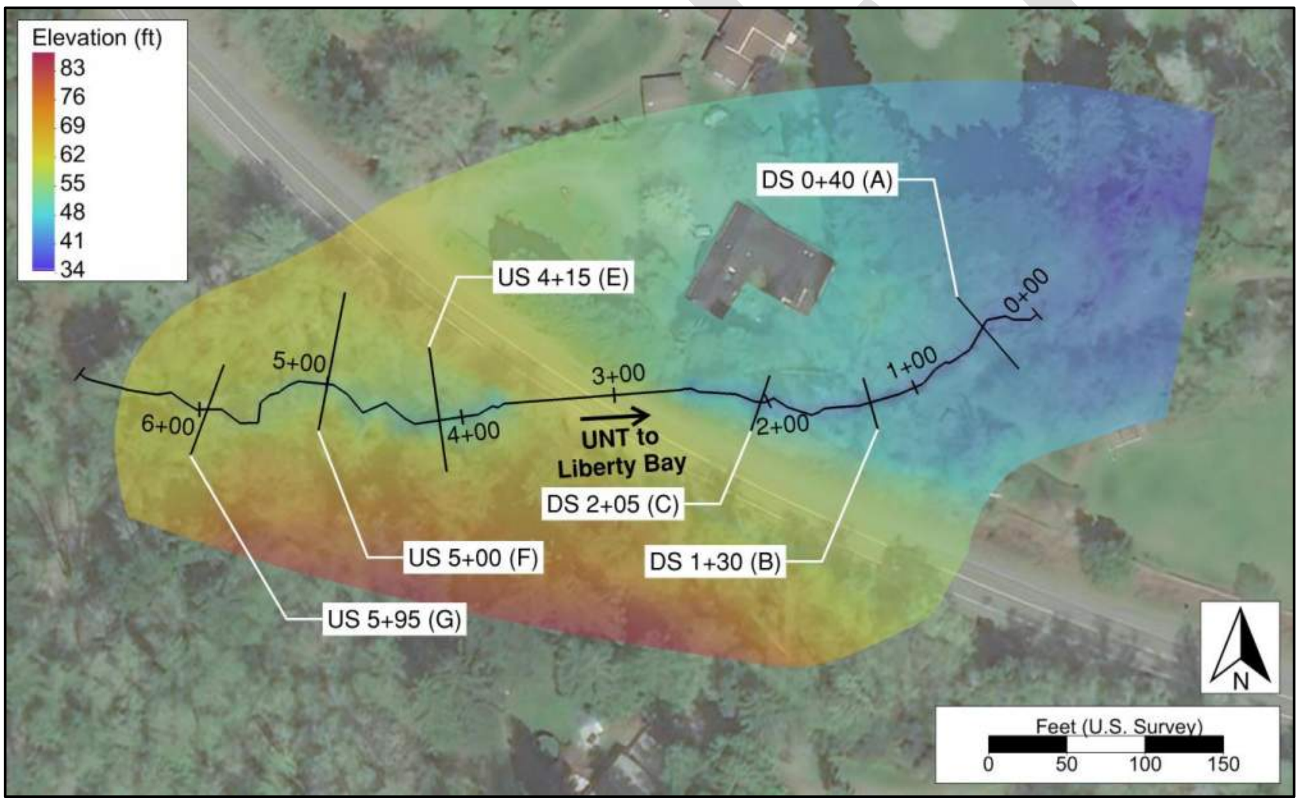

Figure 51: Locations of cross sections used for results reporting

Table 14: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 0+40 (A)	40.4	40.9	41.3
	DS 1+30 (B)	42.7	43.8	44.5
	DS 2+05 (C)	44.2	45.0	45.7
	Structure 3+12 (D)	NA	NA	NA
	US 4+15 (E)	51.9	60.6	61.4
	US 5+00 (F)	55.1	60.6	61.4
	US 5+95 (G)	58.9	60.6	61.4
Max depth (ft)	DS 0+40 (A)	0.9	1.4	1.8
	DS 1+30 (B)	1.4	2.5	3.2
	DS 2+05 (C)	1.0	1.8	2.6
	Structure 3+12 (D)	NA	NA	NA
	US 4+15 (E)	1.3	10.0	10.8
	US 5+00 (F)	1.4	6.9	7.8
	US 5+95 (G)	1.0	2.8	3.6
Average velocity (ft/s)	DS 0+40 (A)	2.7	5.0	7.3
	DS 1+30 (B)	3.2	5.4	6.3
	DS 2+05 (C)	3.8	6.3	6.5
	Structure 3+12 (D)	NA	NA	NA
	US 4+15 (E)	2.5	0.3	0.5
	US 5+00 (F)	3.7	0.8	1.2
	US 5+95 (G)	2.8	2.6	2.9
Average shear (lb/SF)	DS 0+40 (A)	0.8	1.9	2.5
	DS 1+30 (B)	0.8	1.2	1.4
	DS 2+05 (C)	1.2	1.9	1.9
	Structure 3+12 (D)	NA	NA	NA
	US 4+15 (E)	0.7	0.0	0.0
	US 5+00 (F)	1.3	0.0	0.0
	US 5+95 (G)	0.7	0.3	0.3

Main channel extents were approximated using the 2-year event water surface top widths.

The maximum modeled flow through the existing structure is 160 cfs for the 500-year event. No backwater is observed for the 2-year flow, but significant backwater is observed for both the 100- and 500-year flows due to the undersized existing culvert (see Figure 52). The 500-year peak discharge overtops SR 308. The WSE at the upstream cross section at station 5+00 (cross section F) in Figure 53 depicts backwater from both the 100 and 500-year events.

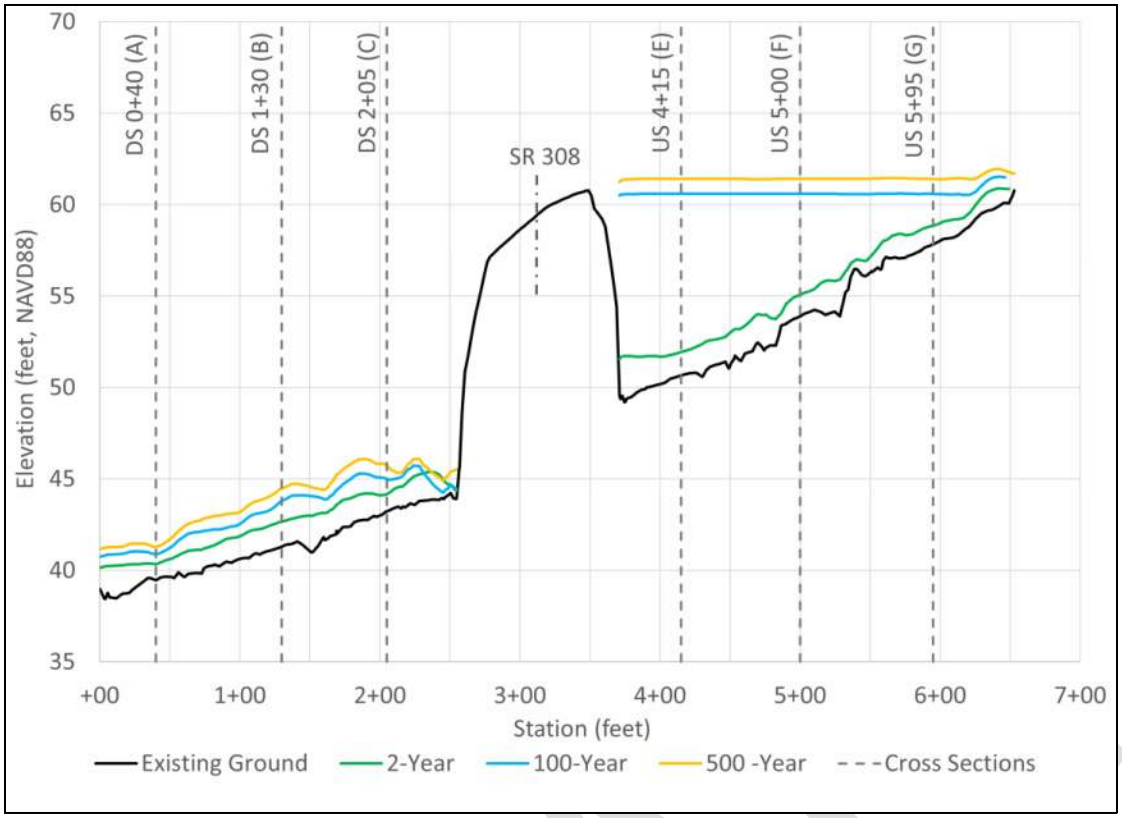

Figure 52: Existing-conditions water surface profiles

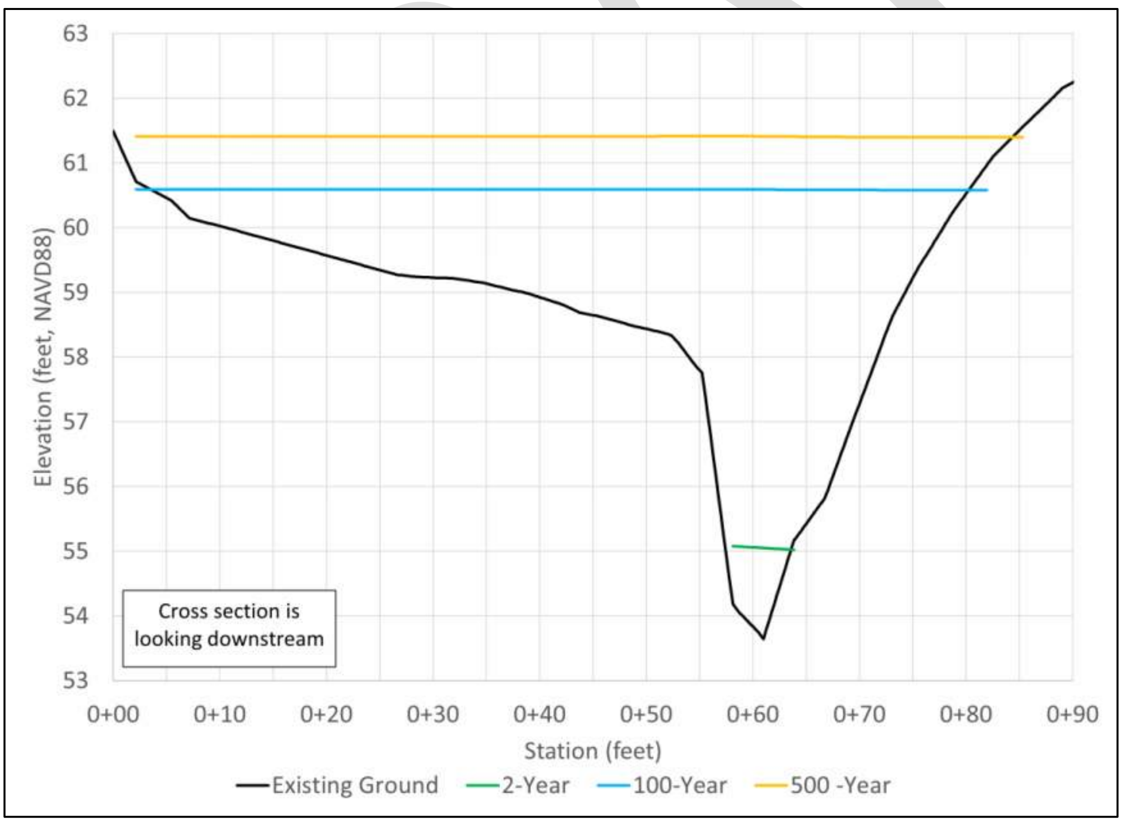

Figure 53: Typical upstream existing channel cross section (Sta. 5+00)

The backwater condition results in slower velocities upstream of the culvert (see Figure 54) due to increased depths, as shown in Figure 55. The backwater condition also results higher velocities (see Figure 54) and shear stress (see Figure 56) at the culvert outlet due to the increased elevation head and pressurized flow. Figure 52 shows decreased WSE at the downstream end of the existing culvert due to the increased velocities at the culvert outlet. These results are consistent with observations of the scour hole at the outlet of the existing culvert. Further downstream, the 100-year velocities generally range between 5.0 feet and 6.3 feet per second (see Table 15). See Section 5.1.6 for discussion of the issues concerning the modeling of existing culverts in SRH-2D using the HY-8 culvert boundary conditions.

See Appendix H for additional SRH-2D existing conditions model results, including: (1) the cross sections in Figure 51 with WSE for all modeled flows, (2) water surface profiles for all modeled flows, and (3) plan view figures for WSE, depth, velocity, and shear stress for all modeled flows.

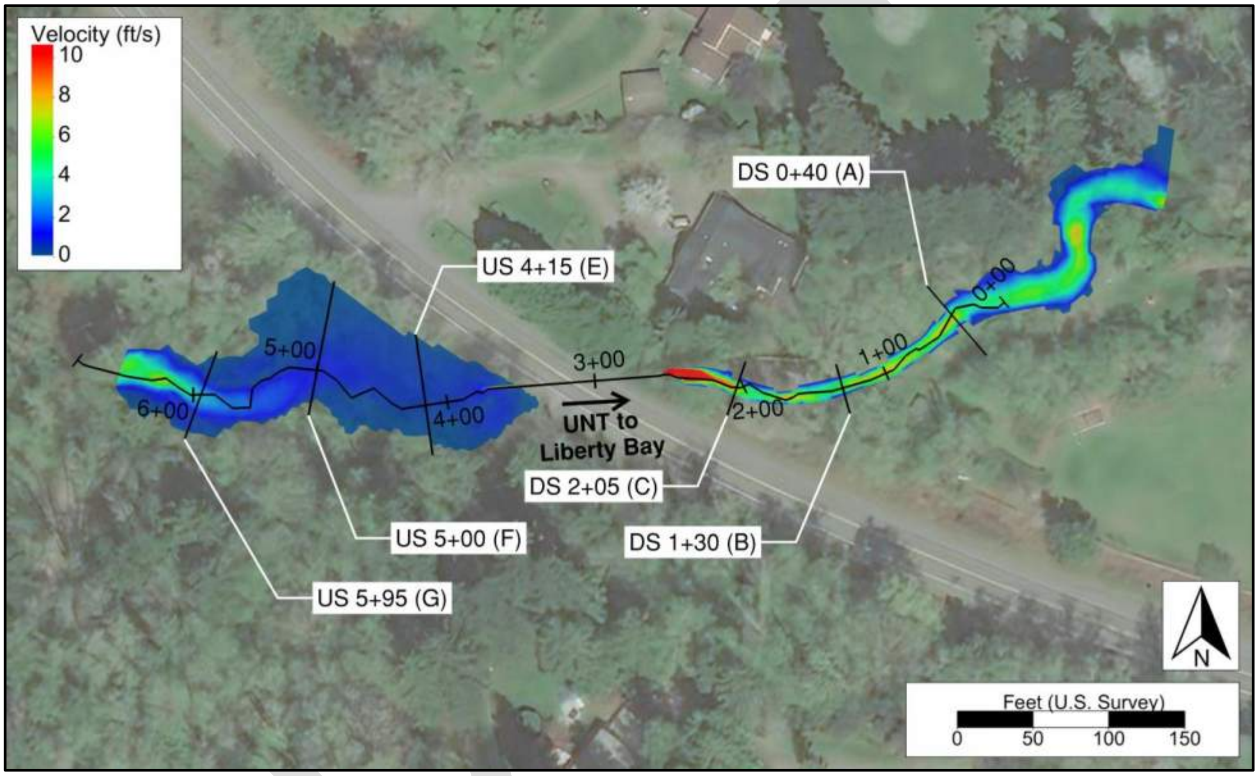

Figure 54: Existing-conditions 100-year velocity map with cross-section locations

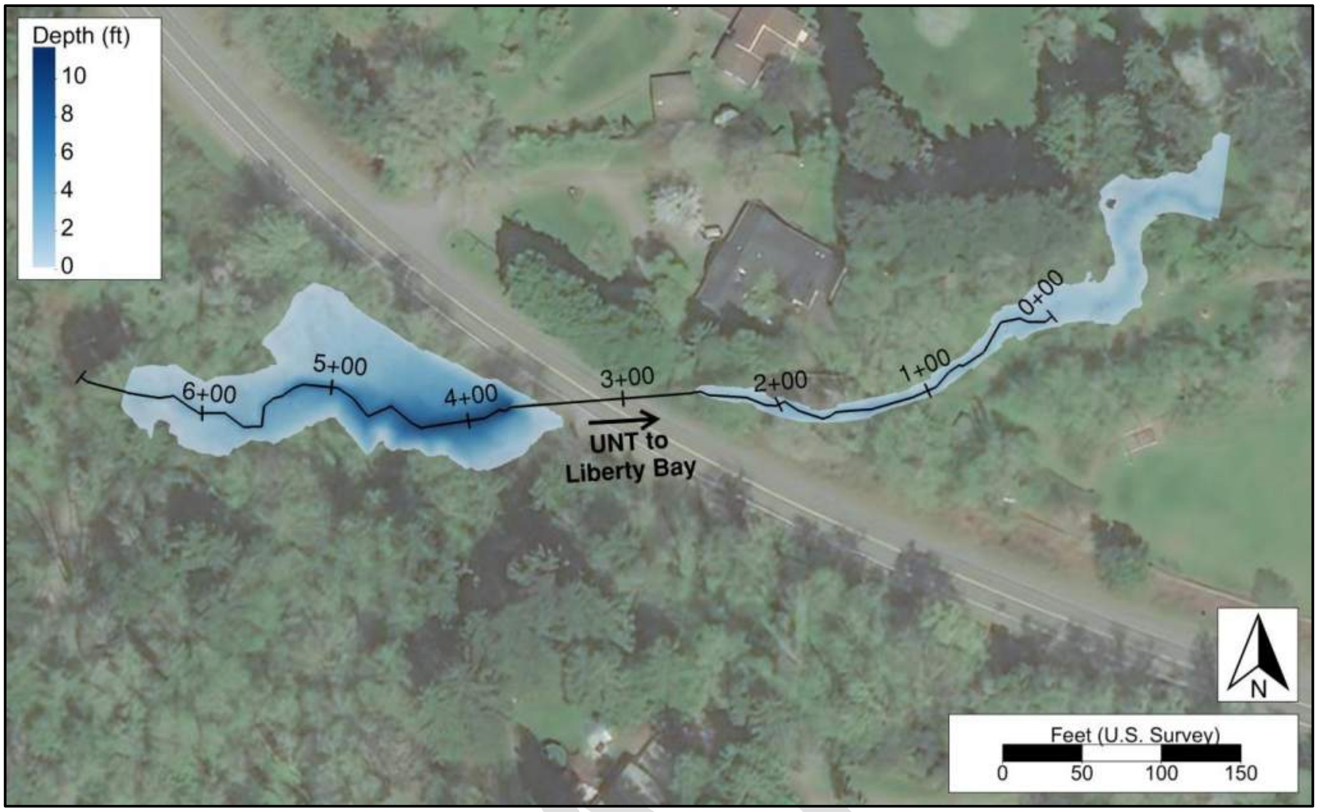

Figure 55: Existing-conditions 100-year depths

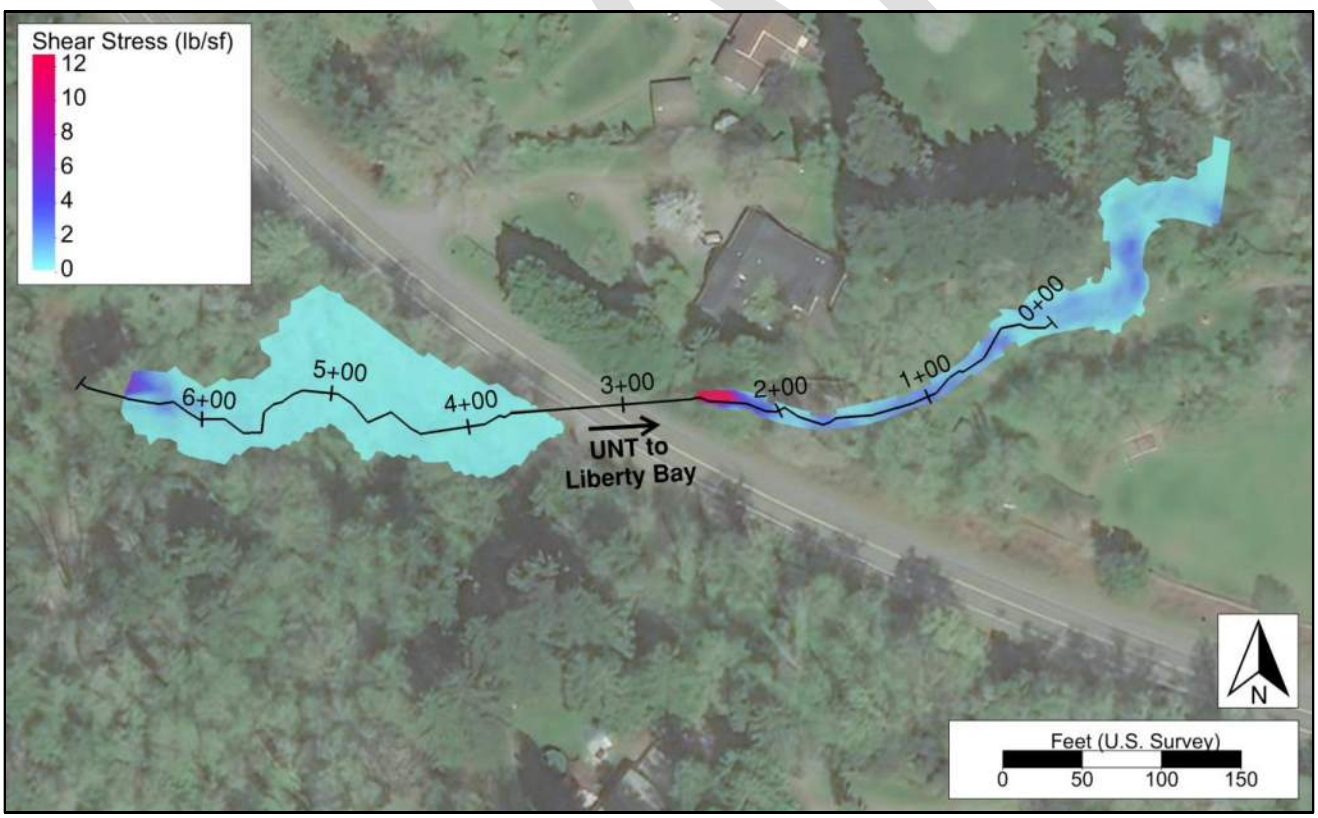

Figure 56: Existing-conditions 100-year shear stress

Table 15: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS - STA 0+40 (A)	1.6	5.0	0.0
DS - STA 1+30 (B)	2.4	5.4	2.8
DS - STA 2+05 (C)	0.0	6.3	0.0
Structure – STA 3+12 (D)	NA	NA	NA
US - STA 4+15 (E)	0.3	0.3	0.1
US - STA 5+00 (F)	0.3	0.8	0.5
US - STA 5+95 (G)	0.5	2.6	0.7

[a]Right overbank (ROB)/left overbank (LOB) locations were approximated using the 2-year event water surface top widths.

5.3 Natural Conditions

A natural-conditions model was not required, because the system is confined.

5.4 Proposed Conditions: 20-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic opening unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

The proposed conditions model uses the same configuration as the existing conditions model except within the extents of the reconstructed channel. In the proposed conditions model, the proposed 20-foot minimum hydraulic opening was represented by revisions to the topographic data and the mesh (see Section 5.1.1 and Section 5.1.2). The proposed conditions model also includes slight revisions to the boundary conditions coverage and materials layers, as discussed in Section 5.1.3 and Section 5.1.4.

Results for the proposed conditions hydraulic model were extracted using observation arcs in SMS:SRH-2D. Three cross sections were placed at locations that represent typical downstream conditions, and another three were placed at locations that represent typical upstream conditions. The proposed cross sections are located at the same stations as those used to extract results from the existing conditions hydraulic model, shown in Figure 51, except another cross section was added that represents the middle of the proposed structure. Figure 57 shows the locations of the cross sections where data were extracted from the proposed conditions model. Cross sections E and F are located within the reference reach. The results extracted from the proposed conditions model were processed using an Excel spreadsheet to determine average or maximum values within the main channel and the overbank areas for each cross section. The main channel extents were determined from the 2-year flood extents, which approximately match the bankfull channel. See Table 16 for the WSE, velocity, depth, and shear stress from the proposed conditions SRH-2D model for the 2-year, 100-year, 500-year, and projected 2080 100-year peak flows.

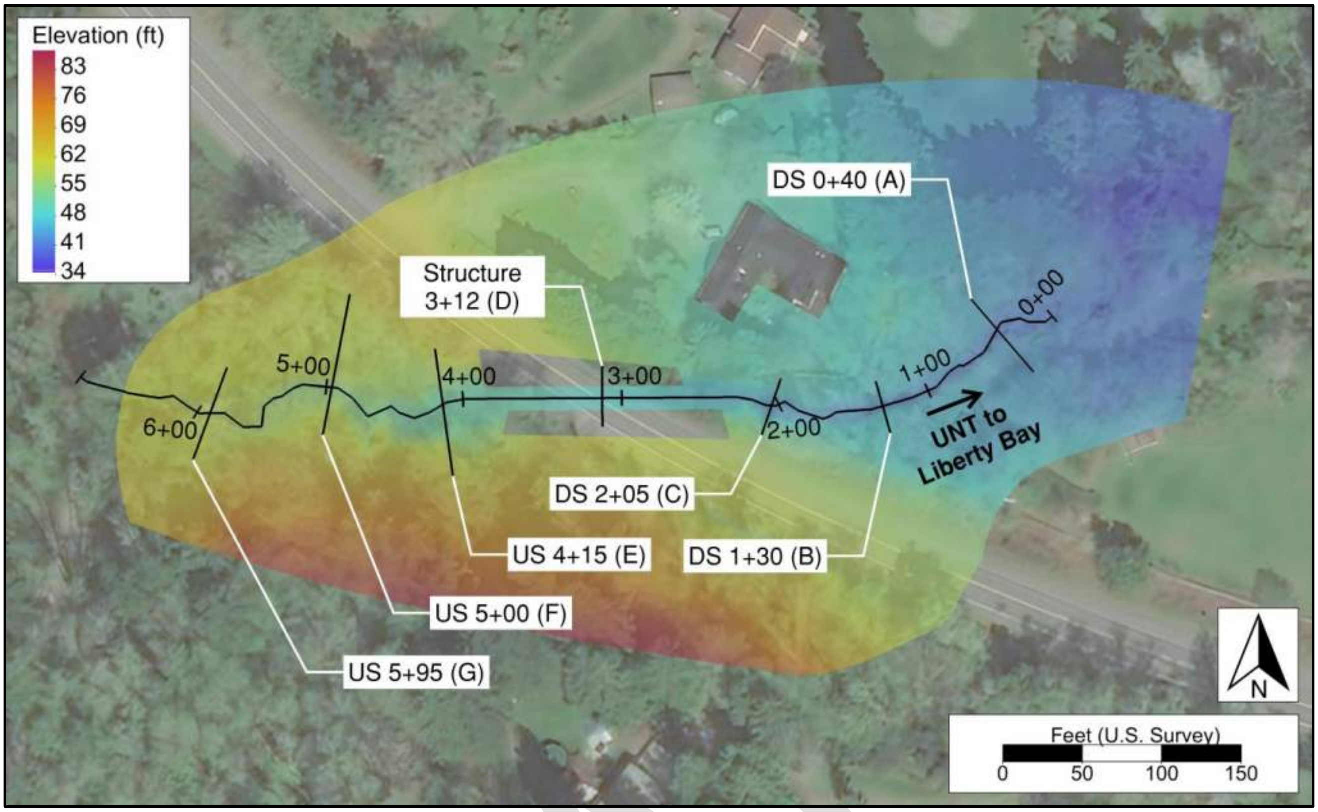

Figure 57: Locations of cross sections on proposed alignment used for results reporting

Table 16: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 0+40 (A)	40.4	40.9	41.3	41.3
	DS 1+30 (B)	42.7	43.8	44.3	44.6
	DS 2+05 (C)	44.2	45.3	46.0	46.3
	Structure 3+12 (D)	47.5	48.2	48.5	48.7
	US 4+15 (E)	51.2	51.9	52.2	52.3
	US 5+00 (F)	55.0	56.1	56.5	56.7
	US 5+95 (G)	58.9	59.5	59.9	60.0
Max depth (ft)	DS 0+40 (A)	0.9	1.4	1.7	1.8
	DS 1+30 (B)	1.4	2.5	3.1	3.3
	DS 2+05 (C)	1.0	2.0	2.8	3.1
	Structure 3+12 (D)	1.0	1.7	2.0	2.2
	US 4+15 (E)	1.3	2.1	2.3	2.5
	US 5+00 (F)	1.4	2.4	2.9	3.1
	US 5+95 (G)	1.0	1.6	2.0	2.1
Average velocity (ft/s)	DS 0+40 (A)	2.7	5.0	6.9	7.5
	DS 1+30 (B)	3.2	5.4	6.3	6.7
	DS 2+05 (C)	3.7	5.3	5.2	5.3
	Structure 3+12 (D)	3.5	6.6	7.5	7.9
	US 4+15 (E)	2.1	3.8	4.3	4.6
	US 5+00 (F)	3.7	6.3	7.5	7.9
	US 5+95 (G)	2.8	5.0	5.5	5.6
Average shear (lb/SF)	DS 0+40 (A)	0.8	1.9	2.3	2.6
	DS 1+30 (B)	0.8	1.2	1.5	1.6
	DS 2+05 (C)	1.1	1.2	1.0	1.1
	Structure 3+12 (D)	1.3	2.3	2.8	3.0
	US 4+15 (E)	1.3	2.5	3.1	3.4
	US 5+00 (F)	1.3	1.7	2.1	2.2
	US 5+95 (G)	0.7	1.3	1.5	1.5

Main channel extents were approximated using the 2-year event water surface top widths.

The proposed hydraulic opening eliminates the existing backwater condition at the SR 308 crossing (see Figure 58 and Figure 59). The velocity results in Table 17 show an increase in 100-year average velocities directly upstream of the structure at station 4+15 compared to existing conditions, but a decrease in 100-year average velocities directly downstream of the structure at station 2+05, compared to existing conditions. This is due to the removal of the existing backwater condition. The 100-year velocities within the proposed structure will be similar to those in the adjacent reaches (see Figure 60). The depths and shear stress within the proposed structure will also be similar to those in the adjacent reaches (see Table 16). These results are expected due to the similarity between the slope and channel geometry of the proposed channel and those of the adjacent reaches.

See Appendix H for additional SRH-2D model results, including: (1) the cross sections in Figure 57 with WSE for all modeled flows; (2) water surface profiles for all modeled flows; and (3) plan view figures for WSE, depth, velocity, and shear stress for all modeled flows.

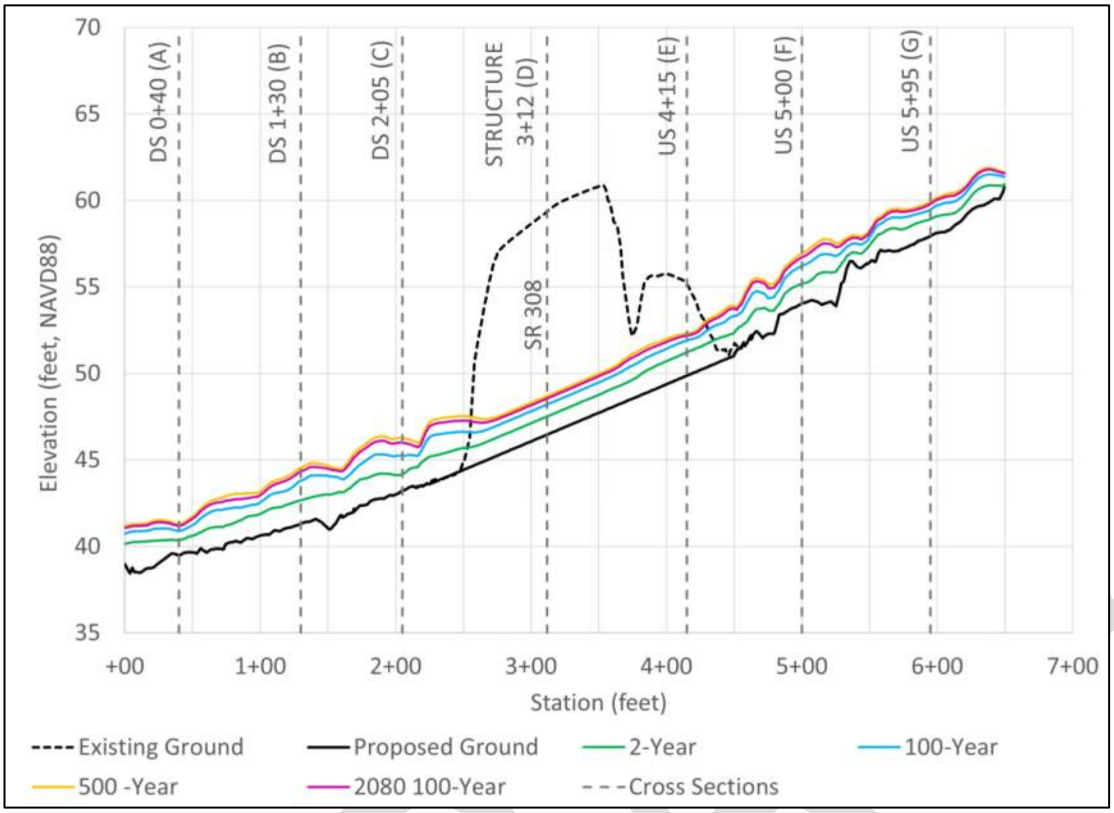

Figure 58: Proposed-conditions water surface profiles

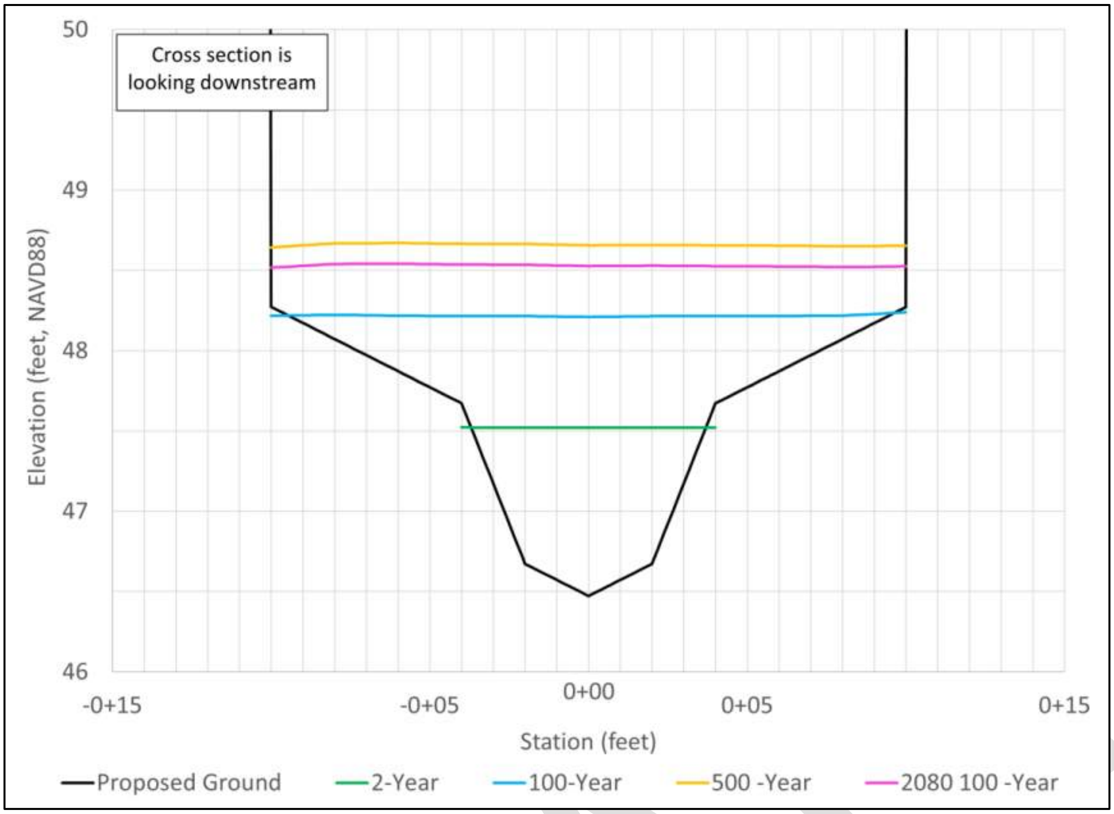

Figure 59: Typical section through proposed structure (Sta. 3+12)

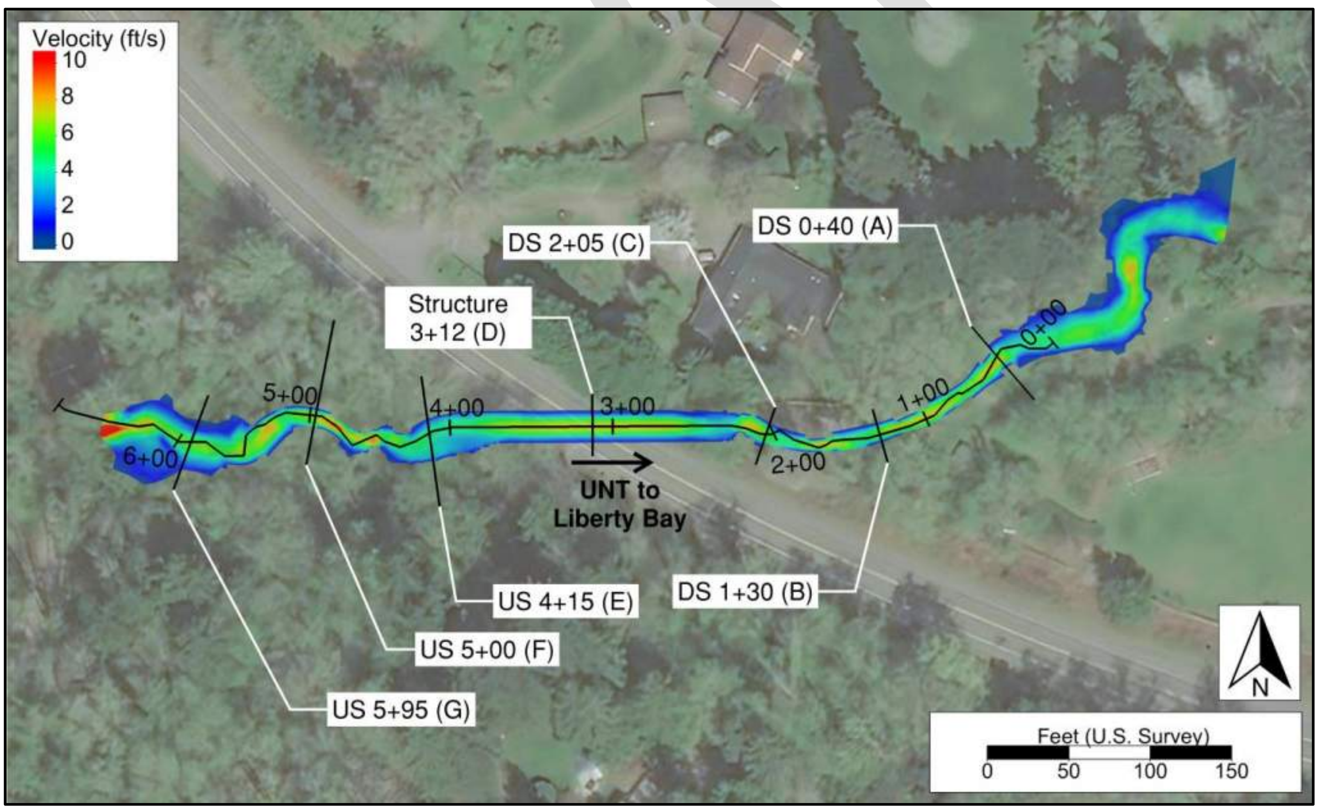

Figure 60: Proposed-conditions 100-year velocity map

Table 17: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 0+40 (A)	1.6	5.0	0.0	2.4	6.9	0.0
DS 1+30 (B)	2.4	5.4	2.8	3.0	6.3	3.4
DS 2+05 (C)	2.6	5.3	1.8	3.4	5.2	1.7
Structure 3+12 (D)	2.7	6.6	2.7	4.2	7.5	4.1
US 4+15 (E)	1.0	3.8	3.3	1.2	4.3	4.7
US 5+00 (F)	3.4	6.3	4.6	4.3	7.5	5.2
US 5+95 (G)	1.3	5.0	2.1	3.4	5.5	2.5

[a]Right overbank (ROB)/left overbank (LOB) locations were approximated using the 2-year event water surface top widths.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA). The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk. Liberty Bay is mapped by FEMA on the Flood Insurance Rate Map panel 53035C0209F (see Appendix A) effective as of February 3, 2017. The 500-year floodplain associated with this UNT to Liberty Bay, and connected with Liberty Bay, comes within approximately 400 feet of the existing culvert outlet (see Figure 61). It is not expected that this floodplain would have an effect on the culvert hydraulics at the crossing location. No high-water marks were found during the site investigation indicating flooding upstream or immediately downstream of the culvert. The figure below shows the project site in the correct location; the flow lines for the channel are slightly inaccurate.

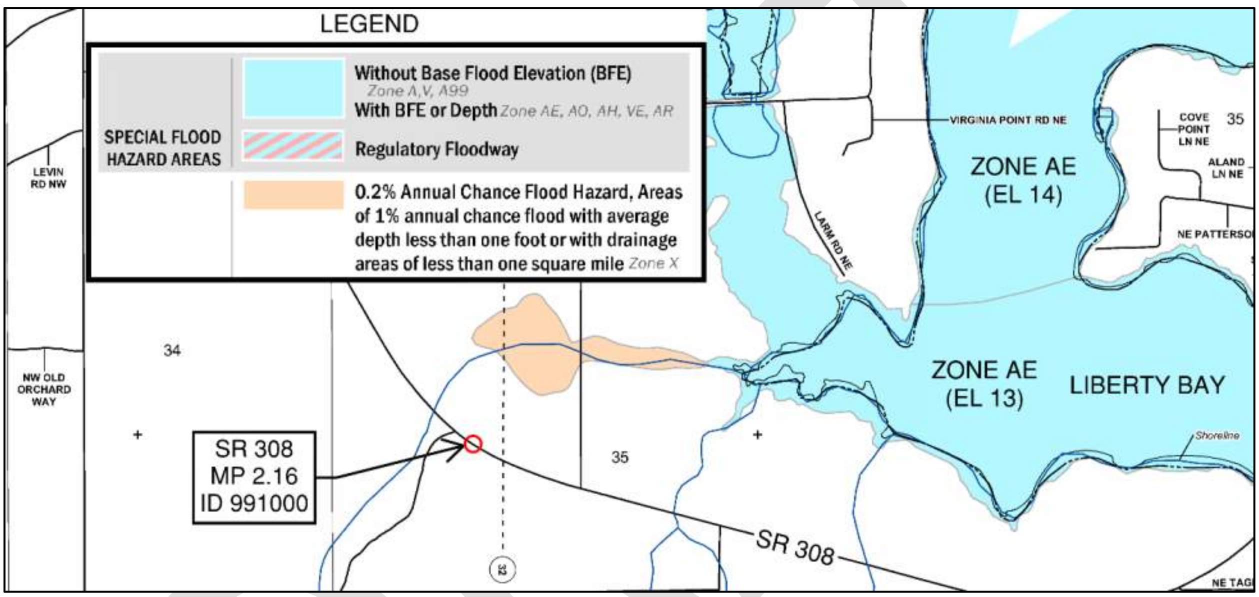

Figure 61. FEMA Floodplain Map

6.1 Water Surface Elevations

A storm with a 100-year return period is usually considered the storm of interest when estimating the effects of flooding or WSE impacts due to a project. Differences in 100-year water surface elevations between existing and proposed conditions are limited to the immediate vicinity of the crossing. Disregarding the lowered WSE immediately upstream of the existing culvert due to remediation of the existing backwater, and the raising of the channel thalweg on the downstream end of the crossing to eliminate the existing scour hole, the WSEs for the 100-year peak flows are essentially identical between the existing and the proposed channel configuration (see Figure 62). The existing and proposed water surface profiles converge at approximately station 1+80 and station 6+30. Figure 63 shows a plan view of the WSE differences. This figure shows any rise greater than zero within the floodplain as a shade of red. However, The proposed channel design does not entail an increased risk to adjacent properties or infrastructure. A flood risk assessment will be developed during later stages of the design.

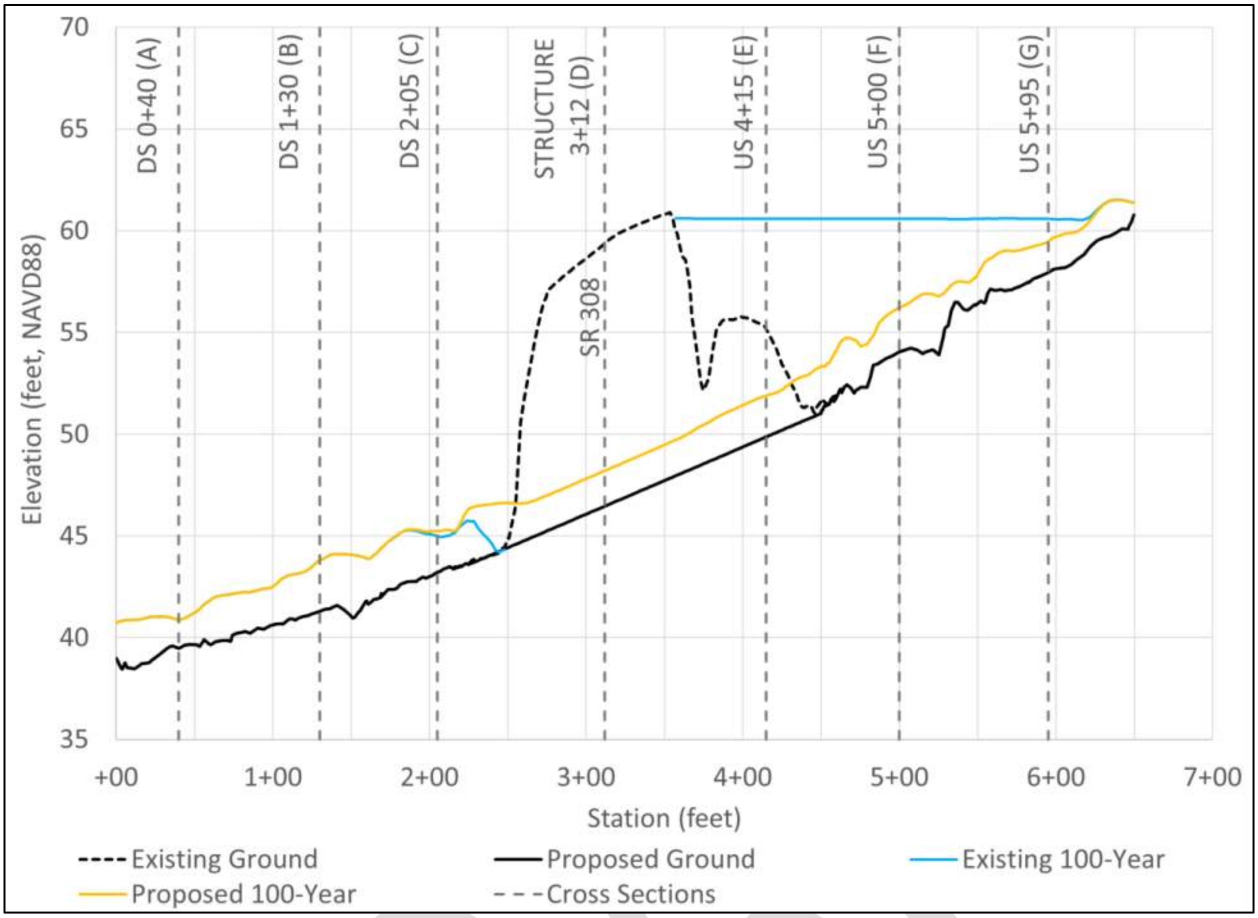

Figure 62: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment

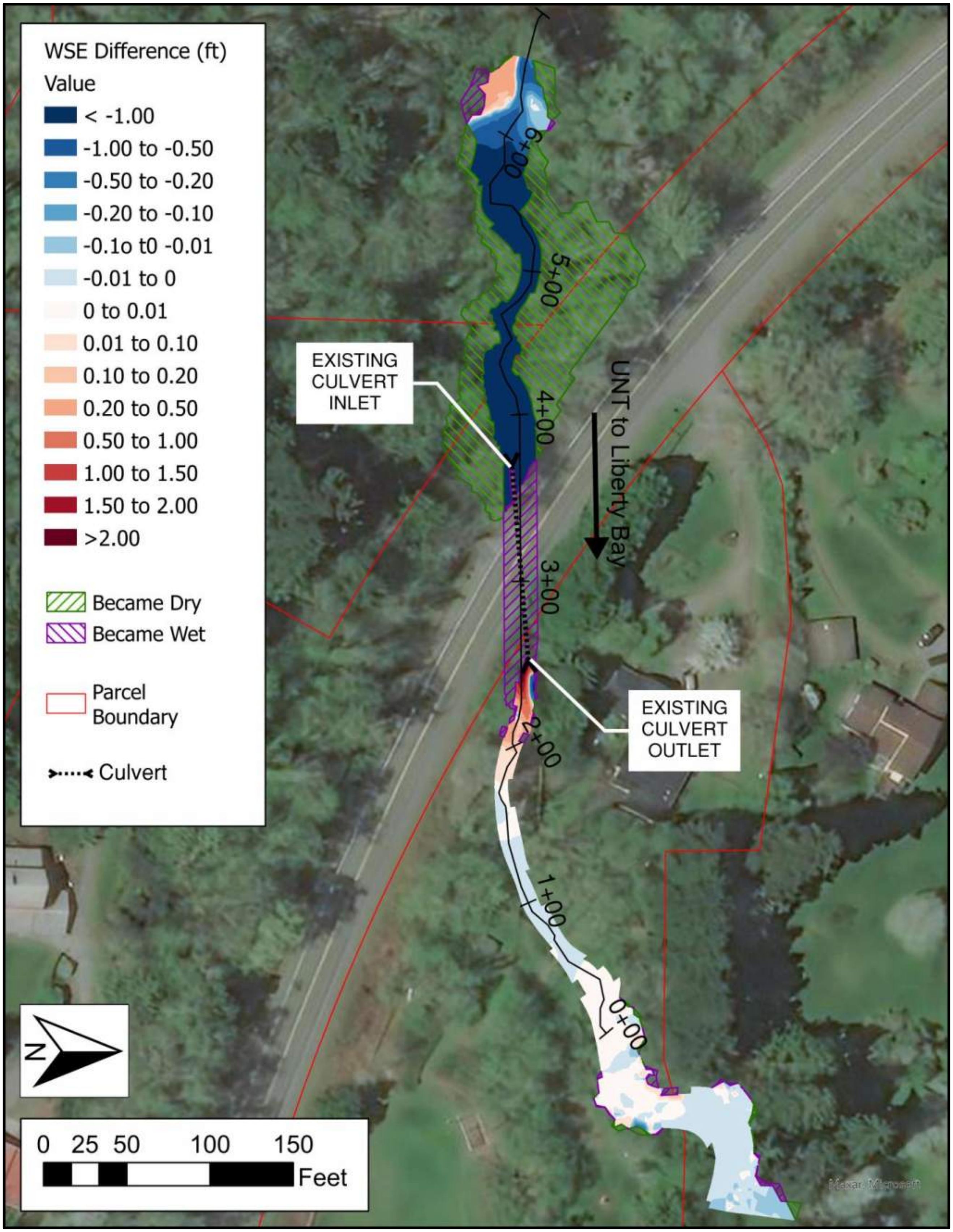

Figure 63: 100-year WSE change from existing to proposed conditions

7 Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation and evaluation of preliminary total scour is based on available data, including but not limited to preliminary geotechnical investigations. This evaluation is to be considered preliminary and is not to be taken as a final recommendation. Using the results of the hydraulic analysis (Section 5.4), based on the recommended minimum hydraulic opening (20 feet) and considering the potential for lateral channel migration, preliminary scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). All peak flows between the 2-year to the 500-year recurrence interval were evaluated to determine which flows resulted in the deepest scour at the structure foundations. The scour design and scour check floods were determined to be the 2080 100-year (135 cfs) and 500-year (160 cfs) events, respectively. Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The project-specific geotechnical scoping memo clarifies that the underlying soils at this site are cohesionless and highly susceptible to erosion. The SR 308 crossing is located within a reach of stream that is incised and sediment starved (see Section 2.7.4), so the proposed design recommends overcoarsened streambed sediment to reduce the risk of post-construction degradation (see Section 4.3.1). However, approximately 3 feet of aggradation may be expected at this site when the upstream culvert crossing (WDFW ID 996939) is removed (see Sections 2.7.4 and 4.2.3). The channel slope will not be significantly altered by the aggradation; therefore, shear stress and velocity in the future aggraded conditions will likely be similar to proposed conditions. The proposed minimum hydraulic opening has been increased to 20 feet (see Section 4.2.2) to accommodate the meander belt widths measured within the reference reach (see Section 4.1.1). Meander widths for future aggraded conditions may increase due to a less confined channel morphology. Because main channel lateral migration is likely to occur within the proposed structure, abutment scour was evaluated relative to the thalweg elevation and not the streambed elevation at the abutment face (see Section 7.4.2). Potential countermeasures should be addressed during final design once detailed geotechnical information is available, and the structure type is known.

7.2 Long-term Degradation of the Channel Bed

As discussed in Section 2.7.4, there is evidence of vertical degradation downstream of the existing culvert. Vertical incision of 1.5 feet to 2 feet begins at the culvert outlet, extending downstream for about 200 feet. This vertical degradation is likely due to channel modification—most likely straightening—caused by adjacent development, as well as increased velocities and shear stress caused by the undersized existing culvert. In addition, the upstream culvert crossing (WDFW ID 996939) is reducing the sediment supply at the existing SR 308 crossing which is causing additional incision (see Section 2.7.4). In the absence of the existing SR 308 culvert, the stream may tend towards a stable equilibrium slope via a headcut moving upstream (FHWA 2001). The project-specific geotechnical scoping memo clarifies that the underlying soils at this site are cohesionless and highly susceptible to erosion (WSDOT 2022c). Coordination with HQ Geotechnical during a meeting on March 16, 2023 confirmed that no subsurface base level controls are evident downstream of the crossing. Since there is no clear, discrete, base level control for this site, the long-term degradation was estimated based upon a stable channel reasonably far downstream (approximately 900 feet) of the SR 308 crossing. This 2.0 percent channel slope extends from the Virginia Loop Road NE crossing (WDFW ID 996938) to Liberty Bay, approximately 1,600 feet downstream of the SR 308 crossing. The 2.0 percent channel slope was projected upstream to provide an estimate of the long-term equilibrium slope through the SR 308 crossing (see Figure 64). This results in an estimated 3.0 feet of potential degradation at the upstream limits of the proposed channel grading. This is a conservative estimate of long-term degradation. An overcoarsened streambed mix is proposed in order to reduce risks of post-construction degradation (see Section 4.3.1). Note that aggradation is also anticipated if the upstream culvert crossing is removed (see Section 2.7.4 and 4.2.3).

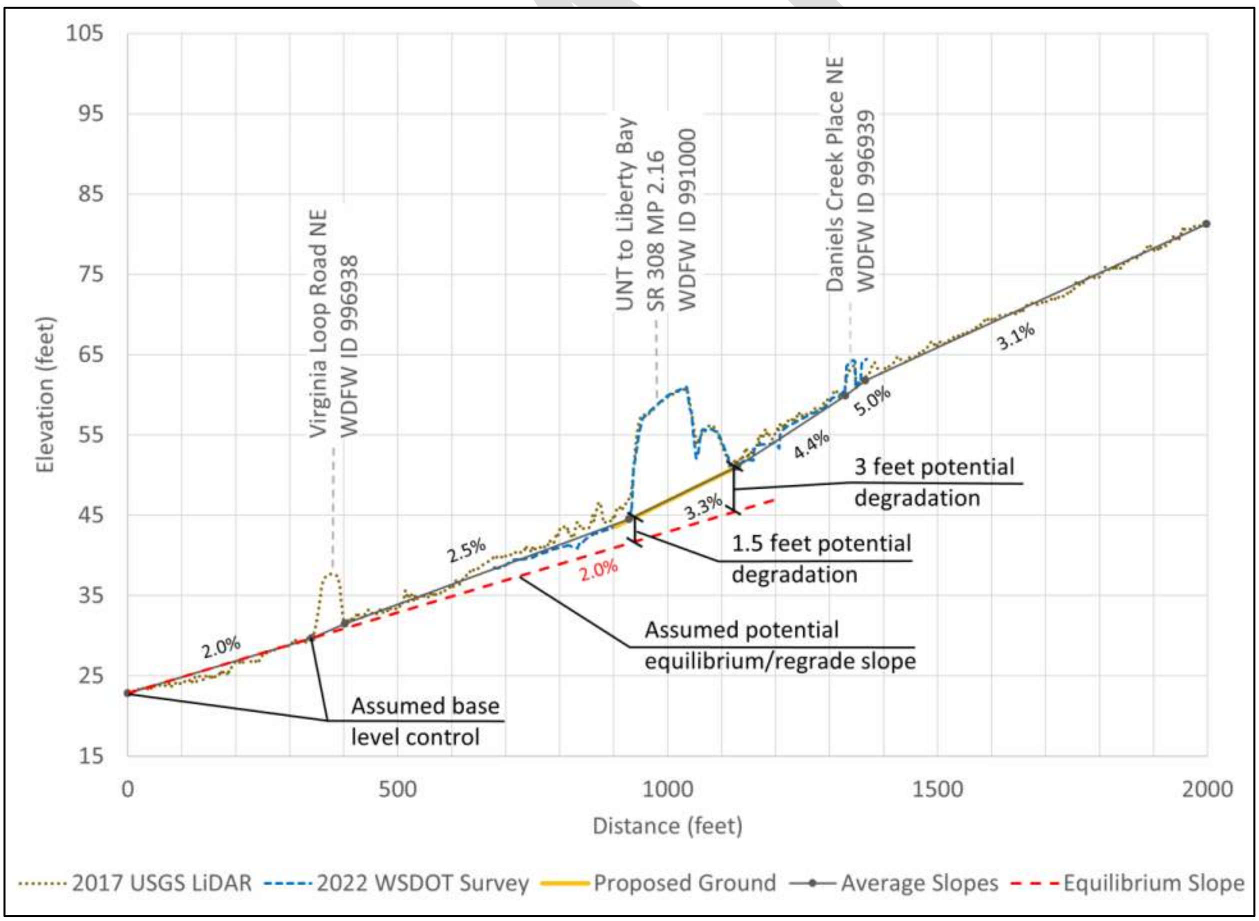

Figure 64: Potential long-term degradation at the proposed structure

7.3 Contraction Scour

The 2-year, 10-year, 25-year, 50-year, 100-year, 2080 100-year, and 500-year events were evaluated for contraction scour. Both clear water and live bed scour conditions were analyzed in Hydraulic Toolbox. Clear water scour was determined to occur for the 2- to 100-year recurrence intervals due to clear water conditions directly upstream of the crossing and extending approximately 50 to 70 feet upstream depending on the recurrence interval. Clear water conditions occur due to an increase in the Manning's roughness of the proposed channel which represent the proposed large woody material. The large woody material will slow velocities and cause sediment to settle. The critical velocity index shows that live bed scour exists during the 2080 100-year and 500-year flow events. Live bed was determined due to significant live bed conditions in the stream, despite a small 15-foot gap of clear water scour conditions directly upstream of the crossing.

The analysis revealed depths of contraction ranging from 0.0 feet to 0.6 feet . See Appendix K for the Hydraulic Toolbox scour analysis output and SMS Bridge Scour coverage figures, which show the locations of the contracted sections, approach sections, channel centerline, abutments and channel banks as well as the critical velocity index and velocity vector coverages.

7.4 Local Scour

The following sections describe the local scour analysis methodology and results of the local scour components.

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. The abutment scour calculated using the NCHRP methodology includes contraction scour, therefore contraction scour should not be added to total scour since it is part of abutment scour. The scour analysis indicated that clear water scour conditions occur during the 2-year, 10-year, 25-year, 50-year, 100-year recurrence intervals, and live-bed scour conditions will occur during the 2080 100-year and 500-year recurrence intervals.

Because main channel lateral migration is likely to occur within the proposed structure (see Section 7.1), abutment scour was evaluated relative to the thalweg elevation and not the streambed elevation at the abutment face. This method requires that the maximum depth at the thalweg is manually input to the Hydraulic Toolbox, and results in abutment scour depths that are measured relative to the thalweg, not the streambed elevation at the abutment face.

Abutment scour equations estimate depths of scour of 2.1 feet at both the scour design flood (2080 100-year event) and scour check flood (500-year event). See Appendix K for the Hydraulic Toolbox scour analysis output and SMS Bridge Scour coverage figures, which show the locations of the contracted sections, approach sections, channel centerline, abutments and channel banks as well as the critical velocity index and velocity vector coverages.

7.4.3 Bend Scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Table 18 provides the calculated total depths of scour for the scour design flood and scour check flood at the proposed UNT to Liberty Bay abutments, as shown in the plans dated November 2, 2022. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 18.

Based on the preliminary design, there is approximately 5.1 feet of anticipated scour for the design flood (2080 100-year flow event), which includes the conservative estimate of 3.0 feet of long-term degradation (see Section 7.2). The structure foundations will be placed a minimum of 5.0 feet below the thalweg elevation, providing 2.0 feet of clearance between top of the foundations and the potential long-term degradation. The preliminary design for UNT to Liberty Bay specifies a total of 5 feet of streambed material within the structure, and 3 feet of streambed material throughout the extents of the constructed open channel (see Appendix D for proposed stream plans). The depth of foundations and streambed sediment should be reevaluated at the FHD stage based upon structure type selected.

Table 18: Scour analysis summary

Calculated Scour Components and Total Scour for SR 308 UNT to Liberty Bay		
Scour component	**Scour design flood (2080 100-year Flow)**	**Scour check flood (500-year Flow)**
Long-term degradation (ft)	3.0	3.0
Contraction scour (ft)[a]	0.6	0.6
Abutment scour (ft) [a]	2.1	2.1
Total depth of scour (ft) [a]	5.1	5.1

[a] Depths are measured relative to the channel thalweg

8 Scour Countermeasures

Scour countermeasures are not proposed for this crossing at the PHD stage. The need for scour countermeasures should be reevaluated at the FHD stage. Proposed scour countermeasures shall not encroach within the minimum hydraulic opening, and structure foundations shall not rely upon scour countermeasures (WSDOT 2022a). Proposed countermeasures should consider right-of-way and other constraints such as adjacent infrastructure. See Figure 41 and Figure 42 in Section 4.3.2.1, as well as the construction plans in Appendix D, for plan views of the proposed design concept and adjacent infrastructure which may need to be removed and/or relocated for this project and its potential scour countermeasures.

9 Summary

Table 19 presents a summary of the results of this PHD Report.

Table 19: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	5,170 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	7.5 ft	2.7.2 Channel Geometry
	Concurrence BFW	7.5 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	15.4 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	2.1	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	84.6 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	135 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	Yes	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	1.9 percent	2.6.2 Existing Conditions
	Reference reach	3.8 percent	2.7.1 Reference Reach Selection
	Proposed	3.30 percent	4.1.3 Channel Gradient
Hydraulic width	Existing	2.5 ft	2.6.2 Existing Conditions
	Proposed	20 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	1.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Required 10 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	114 ft	2.6.2 Existing Conditions
	Proposed	60 ft-130 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	NA	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material

Stream crossing category	Element	Value	Report location
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	No	4.3.2 Channel Complexity
	Boulder clusters	6	4.3.2 Channel Complexity
	Coarse bands	No	4.3.2 Channel Complexity
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	Not significant	6 Floodplain Evaluation
Scour	Analysis	See link	7 Scour Analysis
	Scour countermeasures	Determined at final hydraulic design	8 Scour Countermeasures
Channel degradation	Potential?	0 ft-3 ft degradation possible	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

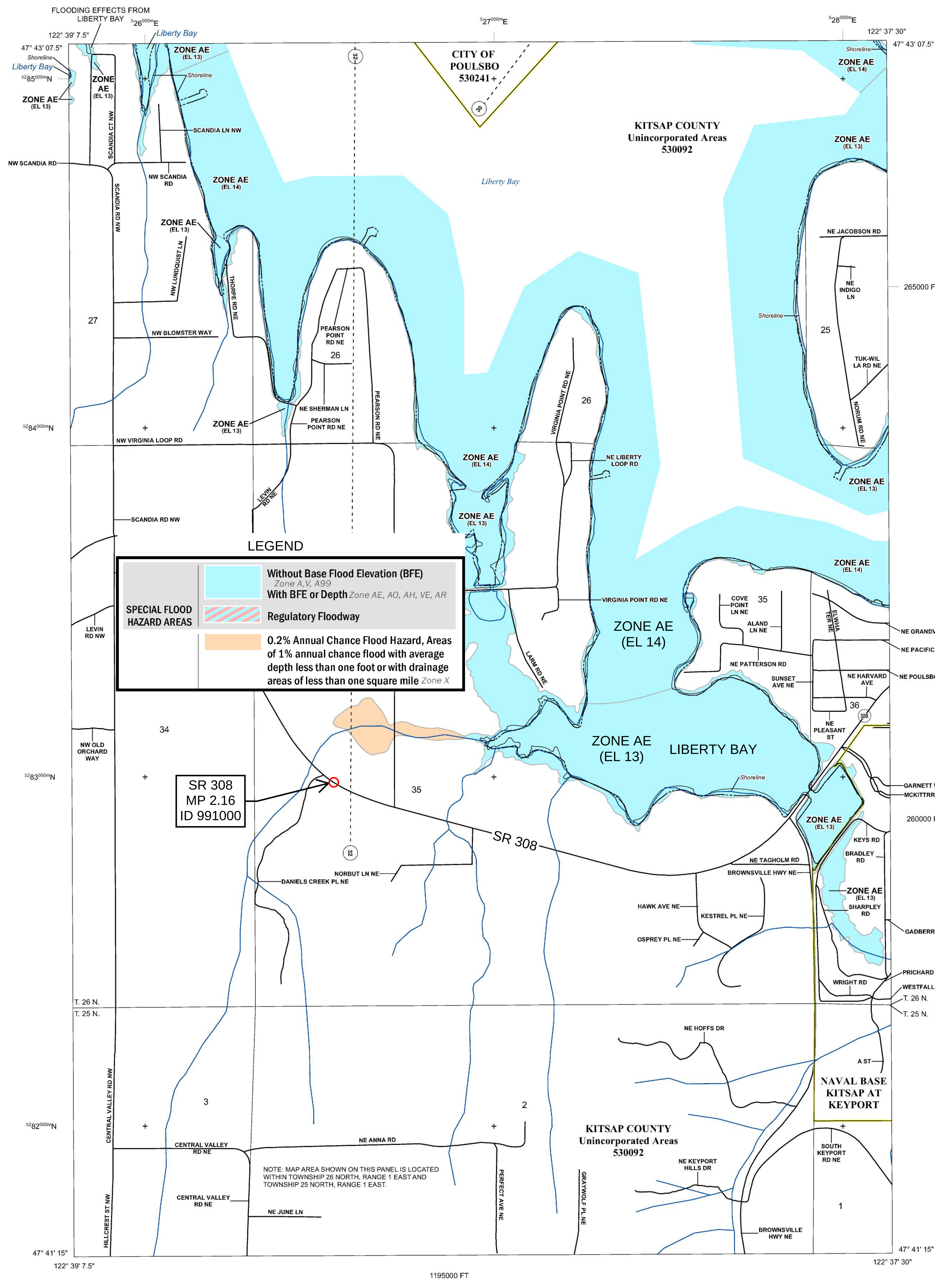
Appendix J: Reach Assessment (NOT USED)

Appendix K: Preliminary Scour Calculations

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Hydrology Calculations

Appendix A: FEMA Floodplain Map



FLOOD HAZARD INFORMATION

SEE FIS REPORT FOR ZONE DESCRIPTIONS AND INDEX MAP

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT

HTTP://MSC.FEMA.GOV

SPECIAL FLOOD HAZARD AREAS	Without Base Flood Elevation (BFE) *Zone A,V, A99*
	With BFE or Depth *Zone AE, AO, AH, VE, AR*
	Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD	0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
	Future Conditions 1% Annual Chance Flood Hazard *Zone X*
	Area with Reduced Flood Risk due to Levee See Notes. *Zone X*
OTHER AREAS	NO SCREEN Areas Determined to be Outside the 0.2% Annual Chance Floodplain *Zone X*
	Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES	Channel, Culvert, or Storm Sewer
	Accredited or Provisionally Accredited Levee, Dike, or Floodwall
	Non-accredited Levee, Dike, or Floodwall
OTHER FEATURES	E 18.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation (BFE)
	8 Coastal Transect
	Coastal Transect Baseline
	Profile Baseline
	Hydrographic Feature
	513 Base Flood Elevation Line (BFE)
	Limit of Study
	Jurisdiction Boundary

NOTES TO USERS

For information and questions about this map, available products associated with this FIRM including historic versions of this FIRM, how to order products or the National Flood Insurance Program in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Map Service Center website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website. Users may determine the current map date for each FIRM panel by visiting the FEMA Map Service Center website or by calling the FEMA Map Information eXchange.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Map Service Center at the number listed above.

For community and countywide map dates refer to the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in the community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

Base map information shown on this FIRM was provided in digital format by Washington State GIS, Kitsap County GIS and Kitsap County Auditor and Elections.

SCALE

N

Map Projection:
NAD 1983 UTM Zone 10N;
Western Hemisphere; Vertical Datum: NAVD 88

1 inch = 500 feet 1:6,000

0 500 1,000 2,000 Feet

0 125 250 500 Meters

PANEL LOCATOR

* PANEL NOT PRINTED

FEMA

National Flood Insurance Program

NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP

KITSAP COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL **209** OF **525**

FEMA

Panel Contains:

COMMUNITY	NUMBER	PANEL	SUFFIX
KITSAP COUNTY	530092	0209	F
POULSBO, CITY OF	530241	0209	F

VERSION NUMBER
2.2.2.1

MAP NUMBER
53035C0209F

MAP REVISED
FEBRUARY 3, 2017

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554 - Task Order AC
	Project Name: Olympic Region GEC	Date: 11/29/2021
	Project Office: WSDOT HQ Hydraulics Office - Olympic Region	Time of Arrival: 2:00 pm
	Stream Name: Unnamed Tributary	Time of Departure: 3:00 pm
WDFW ID Number: 991000	Tributary to: Puget Sound	Weather: Partly Sunny, 55° F
State Route/MP: SR 308 MP 2.16	Township/Range/Section/ ¼ Section: Township 26 North, Range 01 East, Section 35	Prepared By: Micco Emeson
County: Kitsap	Purpose of Site Visit: Site Visit 2- Stream Assessment, Project Constraints	WRIA: 15.0278

Meeting Location:

15244 Silverdale Way NW, Poulsbo, WA 98370

Attendance List:

Name	Organization	Role
Micco Emeson	David Evans and Associates, Inc.	Lead PHD Author
Josh Owens	David Evans and Associates, Inc.	Geomorphologist
Atalia Raskin	David Evans and Associates, Inc.	Senior Engineer
Mike Rice	David Evans and Associates, Inc.	Senior Engineer
Rachel Krulc	David Evans and Associates, Inc.	Junior Engineer
Ryan Barkie	David Evans and Associates, Inc.	Junior Engineer

Bankfull Width:

Three bankfull width (BFW) measurements were taken within the reference reach (BFW-2, BFW-3 and BFW-4), located upstream of the existing culvert. The average of these measurements is 6.83 feet. An additional bankfull width (BFW-1) was measured downstream of the existing culvert. See Figure 1 for bankfull width measurements locations.

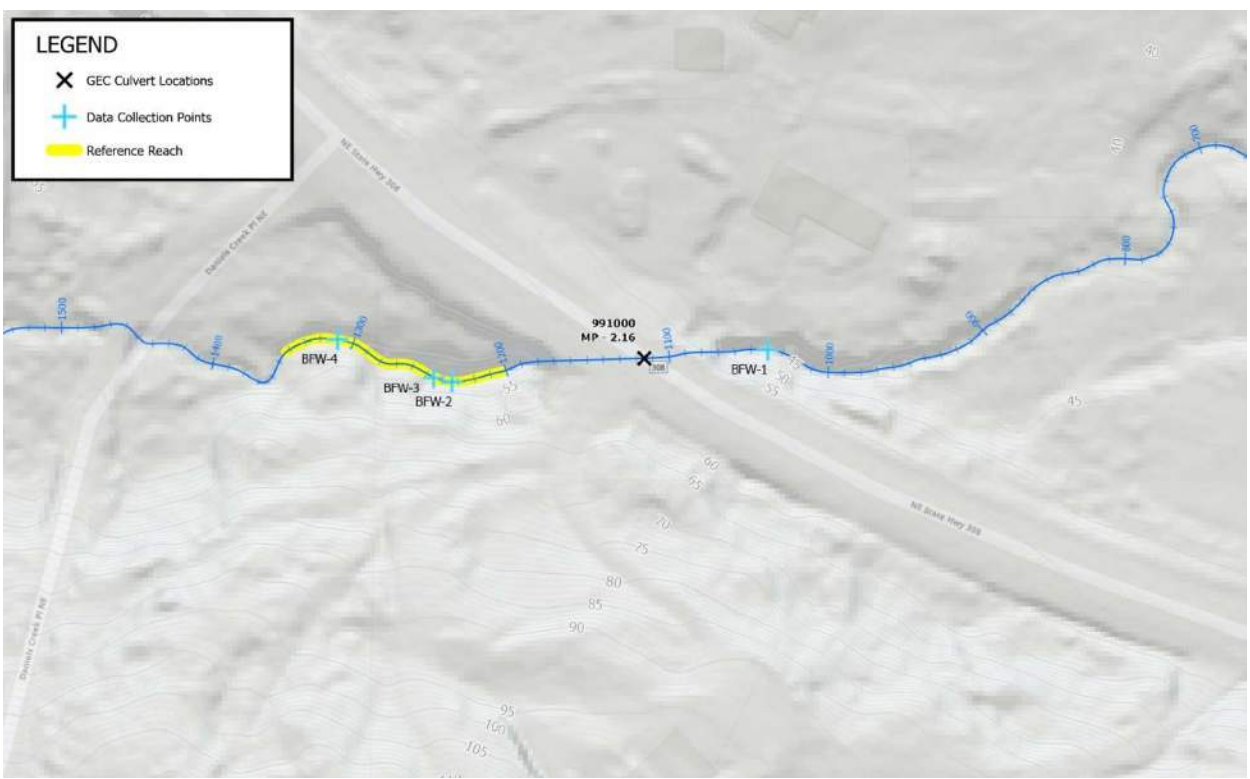


Figure 1.Bankfull Width Measurement Locations

BFW-1 was measured approximately 25 feet downstream of the culvert outlet. Measured BFW was 4.5 feet. This section of stream was modified by adjacent property owners, so the BFW was not considered in the average BFW approximation for the stream (Figure 2).

Figure 2. BFW-1 Measurement

BFW-2 was measured within the reference reach approximately 40 feet upstream of the culvert inlet. Measured BFW was 7 feet (Figure 3).

Figure 3. BFW-2 Measurement

BFW-3 was measured within the reference reach approximately 60 feet upstream of the culvert inlet. Measured BFW was 6 feet (Figure 4).

Figure 4. BW-3 Measurement

BFW-4 was measured within the reference reach approximately 125 feet upstream of the culvert inlet. Measured BFW was 7 feet (Figure 5). This measurement was taken at the midpoint of a plunge pool downstream of a 6-inch drop in the channel. This location represents the widest expected bankfull width within the reference.

Figure 5. BFW-4 Measurement

Reference Reach:

The reference reach is a 140-foot segment of stream that begins approximately 15 feet upstream of the culvert inlet, extending to a distance approximately 155 feet upstream of the culvert inlet. There was no evidence of scour or deposition at the upstream end of the culvert indicating that the culvert is not capacity limited and that there is little upstream hydraulic influence caused by the culvert.

The channel downstream of the culvert was not suitable for a reference reach because there was evidence of scour, bank erosion, and channel incision directly downstream of the culvert for about 200 feet. This may have been caused by channel modifications from adjacent landowners that straightened the channel. The channel appears to take a more natural form further downstream with less incision, but also appears to be widened by human activities.

The reference reach exhibits a combination of gravel and cobble plane-bed sections interspersed with step-pool features caused by woody material. The step heights are generally 6 inches or less, spaced approximately 25 to 35 feet apart. The pool features were filled with coarse to fine sand with no evidence of silts (Figure 6 and Figure 7). Large boulder or bedrock steps were not observed in the field.

The reference reach is relatively confined, having a steep hillslope with no overbank areas on the south side of the channel (right bank looking downstream). There is some flat overbank area on the north side of the channel which is potentially accessible to flood flows (left bank looking downstream), but it is probable that the majority of the 100-year flow of 22 cfs (predicted by Streamstats) could be contained within the channel banks. The channel banks are not steep or incised, but well vegetated, and do not show signs of recent erosion (Figure 7). These are indications that natural channel forming processes have established a relative equilibrium within the reference reach. The 2-3 percent slope of the reference reach is steeper than the channel downstream of the culvert, which flattens to less than 2 percent.

Figure 6. In-Channel Woody Debris

Figure 7. Plunge Pool Caused by Woody Debris and Riparian Vegetation

Data Collection:

Data was collected by staff engineers from David Evans and Associates, Inc. on November 29th, 2021. The field crew included the lead author for the PHD at this site, both junior engineers and senior engineers with experience in data collection for Fish Passage projects, and a Geomorphologist. The downstream end of the site was visited first. Observations were recorded, including a pebble count and bankfull width measurement. Next, the upstream side of the culvert was visited. It became apparent that the upstream channel was a more appropriate reference reach. Three bankfull width measurements and a pebble count were collected within the reference reach. The site was visited again on December 1st, 2021 with two Biologists from DEA, who made observations regarding the habitat benefits of the site. Flow in the channel during these site visits was on the order of 1 cubic foot per second or less. See Figure 8.

Figure 8. Flow at the downstream end of the culvert.

Observations:

The site visit occurred during winter baseflow conditions. There was no evidence of recent erosion or aggradation. The culvert inlet was clear of debris and blockage, the culvert outlet was perched approximately 1 foot from invert to water surface elevation. Immediately downstream of the outlet was a small scour pool. The culvert does not appear to limit flows or sediment transport.

Upstream of the culvert the stream lies within a confined valley with steep hillslopes and steep longitudinal profile (visual estimate of 2-3%). Downstream of the culvert the channel transitions to broader alluvial outwash with a flatter longitudinal profile (visual estimate of <1%). The alluvial outwash likely occurred during glacial melt-water periods with higher flows and the existing stream is too small to cause significant movement of this material. Additionally, the downstream channel is well confined within the channel banks and does not appear to be perched above surrounding terrain, which is sometimes the cause of the lateral channel migration associated with alluvial fans. The risk of flooding and rapid stream movement that is typically associated with alluvial outwash settings (alluvial fans) is low.

Upstream of the culvert, the channel exhibits a combination of gravel and cobble plane-bed sections interspersed with step-pool features caused by woody material. The step heights are generally 6 inches or less, spaced approximately 25 to 35 feet apart. The pool features were filled with coarse to fine sand with no evidence of silts (Figure 6 and 7). Large boulder or bedrock steps were not observed in the field. The channel banks are not steep or incised, but well vegetated, and the overbank areas are accessible to flood flows.

For approximately 200 feet downstream of the culvert outlet the channel is straight and incised with a gravel/cobble plane bed and steep stream banks formed of cohesive materials. There were no signs of recent bank erosion and this configuration appears to be relatively stable. About 100 feet downstream of the culvert there was a large stump (3 feet high x 4 feet wide) in the middle of the stream that caused left bank widening of about 2 feet without any major slumping or undercutting (

Figure 9). The incision in this section is likely due to channel adjustment as a response to straightening and over-steepening. Downstream of this incised section the channel is no longer straight and incised, and the bed consists of a combination of both coarse and fine materials. The channel widens due to reduced channel slope, reduced bank vegetation, and potential human and animal use (Figure 10).

Figure 9. Channel Widening and Bank Incision due to Stump

Figure 10. Modified Channel Downstream of Incised Channel

Pebble Counts:

Two Wolman Pebble Counts (PC) were conducted at this site. See Figure 11 for pebble count locations.

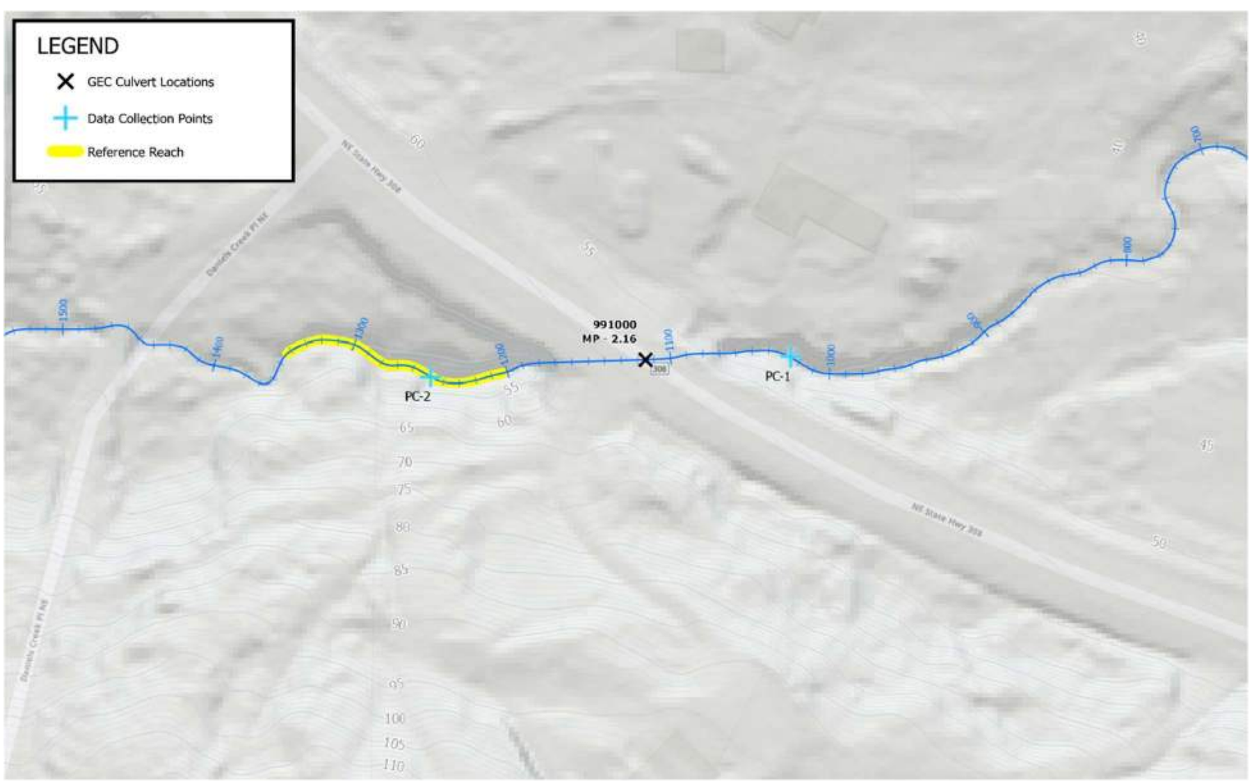


Figure 11. Pebble Count Locations

PC-1 was conducted along a length of stream approximately 30-50 downstream of the existing culvert outlet. The sediment here consisted of coarse sands, gravels, and small cobbles 90 millimeters or less. The sediment at this location was coarsened in comparison to the reference reach due to increased velocities in this reach, evidenced by the scour and erosion mentioned in the reference reach section above. See Figure 12 and Figure 13.

Figure 12. PC-1 Sediment w/ Gravelometer

Figure 13. PC-1 Sediment in Hand

PC-2 was conducted along a length of stream approximately 55-65 feet upstream of the existing culvert inlet. The sediment here consisted of coarse sands, gravels, and small cobbles 64 millimeters or less. See Figure 14 and Figure 15. The pebble count location within the reference reach was taken at a location that exhibited a gravel and cobble plane-bed morphology with few fines because of the more rapid and shallow flow characteristics. Therefore, this pebble count represents the upper size limit of coarse material that could be mobilized by the stream without the influence of wood material or other potential grade controls. In pools this material will become overlaid with sand as was observed within the reference reach.

Figure 14. PC-2 Sediment w/ Gravelometer

Figure 15. PC-2 Sediment in Hand

Photos:
See above.

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☐ If no, then stop here.* *Yes ☒ If yes, then fill out the proceeding section for each sample.*

Sample #:	Work Start:	Work End:	Latitude:	Longitude:
PC-1 and PC-2	Nov. 29, 2021 2:00 p.m.	Nov. 29, 2021 3:00 p.m.	47.70001	-122.64682
Summary/description of location:				
Two Wolman Pebble Counts (PC) were taken at this location. One PC was conducted approximately 30-50 feet downstream of the culvert outlet. Another PC was conducted approximately 55-65 upstream of the culvert inlet.				
Description of work below the OHWL:				
Work within the OHW included Wolman Pebble Counts which consists of walking along the streambed to collect 100 random samples of sediment. These samples are then measured in-situ to determine the gradation of the existing streambed sediment. After being measured the samples are returned to the stream.				
Description of problems encountered:				
Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.				

Concurrence Meeting

Date:	Time of Arrival:
Dec. 17th, 2021	3:00 pm

Prepared By:	Weather:	Time of Departure:
Micco Emeson, PE	Cloudy, scattered showers	4:30 pm

Attendance List:

Name	Organization	Role
Alison O'Sullivan	Suquamish Tribe	Tribal Representative
Amber Martens	WDFW	Biologist
David Collins	WDFW	Biologist
Cade Roler	WSDOT	Hydraulic Engineer
Micco Emeson	DEA	Hydraulic Engineer
Steve Seville	DEA	Hydraulic Engineer

Bankfull Width:

Four bankfull widths were initially measured in the assessed reach (BFW-1, 2,3 and 4); three of them within the reference reach. Each of the BFW measurement locations were visited and discussed with co-managers during the site visit on December 17th, 2021. The co-managers did not concur with one of the initial BFW measurements within the reference reach (BFW-2) which was determined to be within the culvert's zone of influence. The co-managers added two additional BFW measurements beyond the reference reach (BFW-5 and BFW-6) for inclusion in the BFW average (Figure 16). BFW-5 was determined to be 7.5 feet, and BFW-6 was determined to be 8.5 feet. BFW-6 was measured downstream of the culvert outlet, outside of the original reference reach and within an area of apparent channel incision and widening (Figure 17). BFW-5 was measured upstream of the original reference reach within an unconfined area (Figure 18). The inclusion of these new measurements increased the average BFW to 7.3 feet. However, during the site visit and in the follow-up notes the co-managers concurred with an average BFW of 7.5 feet. This is the BFW average used for design.

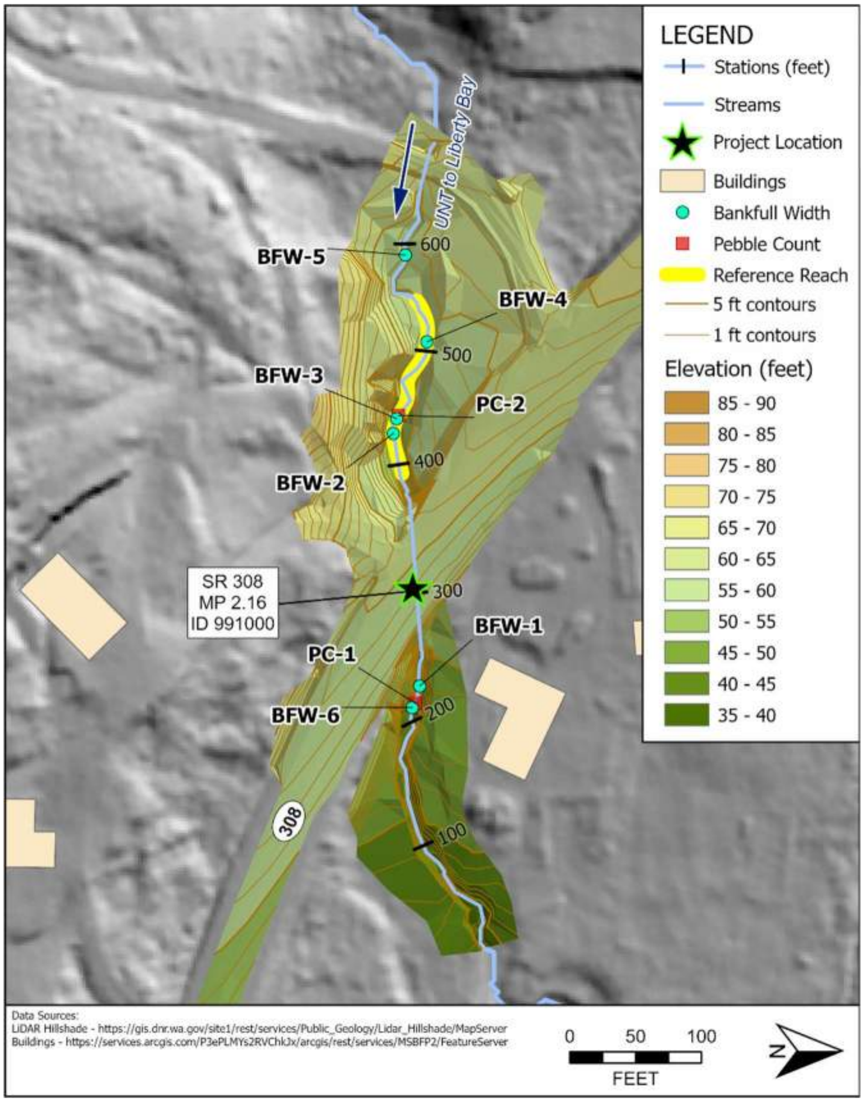


Figure 16. BFW Locations

Figure 17. Approximate BFW-6 Measurement Location

Figure 18. BFW-5 Measurement Location

Reference Reach:

The co-managers agreed that the downstream channel was confined and incised, and not representative of natural conditions within this stream. Nevertheless, an additional bankfull width was measured in this reach for inclusion in the BFW average for design, as previously discussed. The co-managers generally agreed with the location of the reference reach, noting that the stream is confined within the reference reach, but that further upstream the stream is unconfined. A bankfull width was measured within the unconfined stream section, as previously discussed.

Observations:

The co-managers identified the soil banks downstream of the existing culvert as highly erodible soil, conflicting with the preliminary assessment by the Geomorphologist, conducted during the November 29th site visit. The geotechnical conditions at the site have yet to be verified by a qualified geotechnical engineer.

Whether the soils are highly erodible or not, there was evidence of incision in the downstream channel. Consequently, the co-managers specified that bioengineered bank protection may be needed along the banks downstream of the existing culvert if 2:1 slopes cannot be achieved. This is a likely scenario due to roadway and utilities that constrain the grading limits on the right bank, and private property close to the top left bank that shows signs of incision.

During this site visit, the landowners that live adjacent to the downstream reach approached the concurrence party and requested that (1) they be contacted prior to future site visits due to the proximity of the site with their home, and (2) that their riparian plantings be maintained in the proposed design. They voiced displeasure at the WSDOT survey crews that apparently removed some riparian vegetation that they had planted to prevent bank erosion.

To address these concerns and minimize bank erosion adjacent to their property, the co-managers requested that the upstream end of the culvert be skewed away from the hillslope so that the downstream end is directed away from the downstream landowner's property. The co-managers acknowledged that this may result in a longer structure.
The downstream landowner's contact info is below:

- Bethany 360-434-8736
- Andrew 360-434-8758
- Address 208 NE State Hwy 308
- Email RevAndrewBurns@gmail.com

Photos:

No additional photos were taken during the concurrence site visit.

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	**WSDOT OLYMPIC REGION GEC**
WDFW SITE ID:	**991000**
STATE ROUTE/MILEPOST:	**SR 308, MP 2.16**
SITE VISIT DATE:	**December 17, 2021**
ATTENDEES:	**Micco Emeson (DEA), Mike Rice (DEA), Cade Roler (WSDOT), Alison O'Sullivan (Suquamish Tribe), Amber Martens (WDFW)**
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	**High-complexity**
IN WATER WORK WINDOW	**to be provided by WDFW.**

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, “Is follow up needed on this item?” The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading		✓		Minor stream grading to eliminate drop on d/s end of culvert.
Risk of degradation/aggradation		✓		Will need to ensure longitudinal regrade is stable.
Channel realignment		✓		Channel straightened/oversteepened. Realignment may reduce d/s channel slope.
Expected stream movement		✓		Lateral channel migration possibility
Gradient		✓		Will need to regrade to eliminate drop.
Potential for backwater impacts	✓			No existing backwater, no expected backwater impacts.
Meeting requirements for freeboard	✓			Sufficient fill depth to provide adequate freeboard.
Stream size, and Bankfull Width	✓			Stream size is small (<25 cubic feet per second), BFW ~ 7 feet.
Slope ratio			✓	Steeper slope on u/s than d/s end.
Sediment supply	✓			No supply or transport issues expected.
Meeting stream simulation			✓	Slope ratio will be difficult to meet.
Channel confinement		✓		Channel is fairly confined.
Geotech or seismic considerations			✓	Highly erodible soils
Tidal influence	✓			No tidal influence at this site. Channel thalweg EL > 25 feet.
Alluvial fan			✓	Site on an alluvial fan.
Fill depth above barrier	✓			Sufficient for freeboard but not excessively deep.
Presence of other nearby barriers		✓		Upstream barrier at Daniels Creek Place NE.
Presence of nearby infrastructure			✓	Nearby driveways and property lines will limit options.
Need for bank protection			✓	Bank protection possible due to property on d/s end.
Floodplain utilization ratio		✓		Channel is confined without much overbank floodplain area.

Other:				**Navy fiber optic and other nearby utilities.**
				Landowner plantings to be retained on d/s end
				Close coordination and advance notice of construction required with d/s landowners.

Appendix C: Streambed Material Sizing Calculations

Summary - Overcoarsened Bed Material Design

Project:	**UNT to Puget Sound, SR 308 MP 2.16, WDFW ID 991000**
By:	**David Evans and Associates; Micco Emeson, PE**

Design Gradation

Location:	Proposed Channel			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**1.0**	**0.7**	**0.2**	**0.0**
in	**12.0**	**8.1**	**2.4**	**0.6**
mm	**305**	**205**	**61.8**	**14.8**

Existing Gradation

Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.00**	**0.00**	**0.00**	**0.00**
in				
mm	**0**	**0**	**0.0**	**0.0**

Existing Gradation

Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.00**	**0.00**	**0.00**	**0.00**
in				
mm	**0**	**0**	**0.0**	**0.0**

Existing Gradation

Location:	Existing Average			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.3**	**0.1**	**0.1**	**0.0**
in	**3.5**	**1.5**	**0.8**	**0.2**
mm	**90**	**39**	**19.8**	**5.6**

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		**Streambed**	**Streambed Cobbles**					**Streambed Boulders**			**D_{size}**
[in]	**[mm]**	**Sediment**	**4"**	**6"**	**8"**	**10"**	**12"**	**12"-18"**	**18"-28"**	**28"-36"**	
36.0	**914**									**100**	**100.0**
32.0	**813**									50	**100.0**
28.0	**711**								**100**		**100.0**
23.0	**584**								50		**100.0**
18.0	**457**							**100**			**100.0**
15.0	**381**							50			**100.0**
12.0	**305**						**100**				**100.0**
10.0	**254**					**100**	**80**				**96.0**
8.0	**203**				**100**	**80**	68				**83.7**
6.0	**152**			**100**	**80**	68	57				**75.5**
5.0	**127**			**80**	68	57	**45**				**67.3**
4.0	**102**		**100**	71	57	**45**	39				**60.4**
3.0	**76.2**		**80**	63	**45**	38	34				**55.9**
2.5	**63.5**	**100**	65	54	37	32	28				**51.4**
2.0	**50.8**	**80**	50	**45**	29	25	22				**40.9**
1.5	**38.1**	74	**35**	34	21	18	16				**34.7**
1.0	**25.4**	**68**	17	23	13	12	11				**28.4**
0.75	**19.1**	57	**5**	**5**	**5**	**5**	**5**				**20.6**
0.50	**12.7**	46									**13.8**
0.19	**4.75**	**35**									**10.5**
0.017	**0.425**	**13**									**3.9**
0.003	**0.075**	**7**									**2.1**
% per category		**30**	**0**	**0.0**	**0.0**	**50.0**	**20.0**	**0.0**	**0.0**	**0.0**	*100.0%*
% Cobble & Sediment		**30.0**	**0.0**	**0.0**	**0.0**	**50.0**	**20.0**	**0.0**	**0.0**	**0.0**	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

United States Forest Service (USFS)

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E - Methods for Streambed Mobility/Stability Analysis

Range of Suitability:

$D_{84\ ranging}$ between 0.40 in and 10 in

Uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

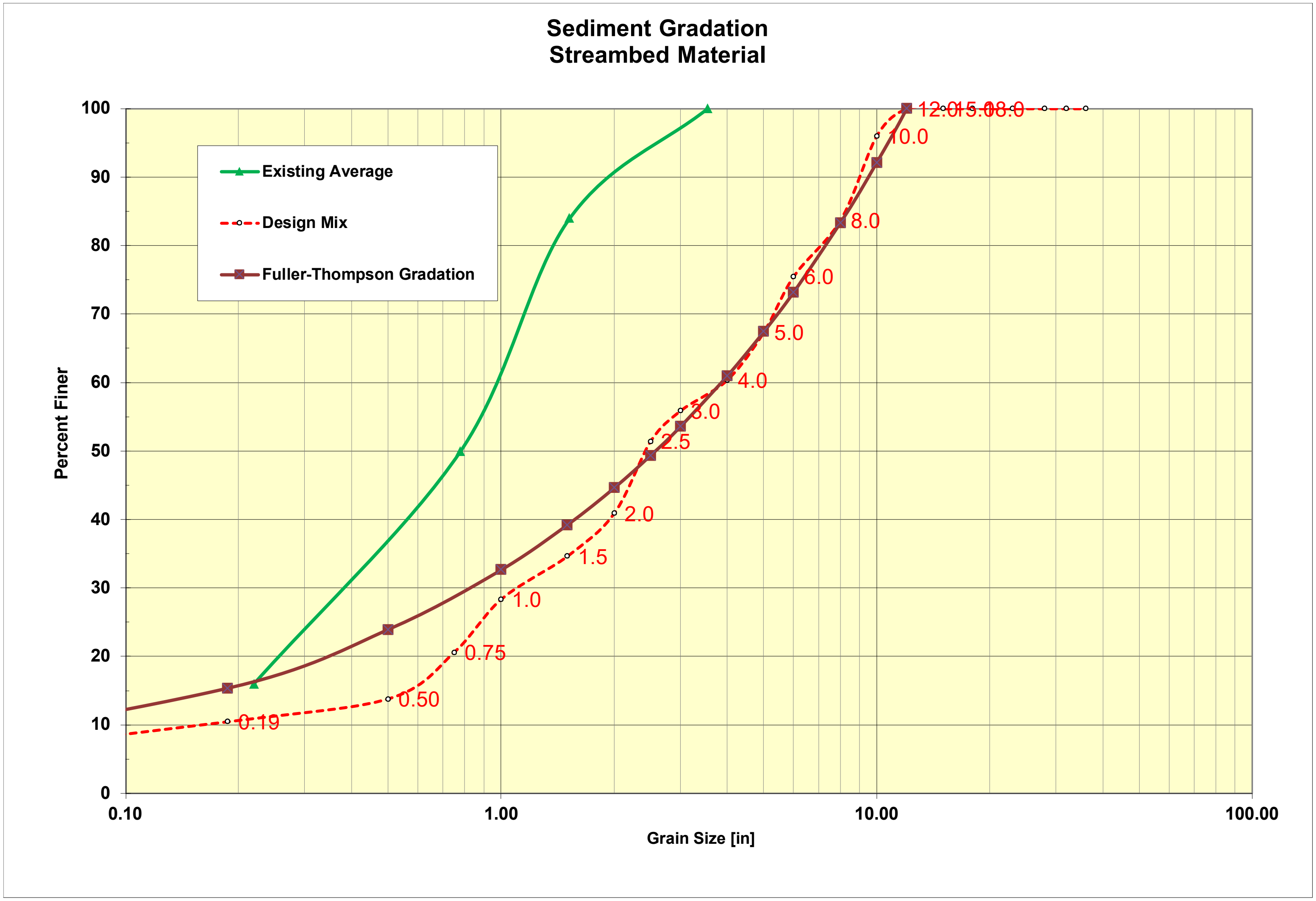
γ_s =	165	specific weight of sediment particle (lb/ft^3)
γ =	62.4	specific weight of water (lb/ft^3)
τ_{D50} =	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

τ_{ci} = the critical shear stress at which the sediment particle of interest begins to move (lb/ft^2 or N/m^2)

Average Modeled Shear Stress (lb/ft^2)

Rock Size [in]	D_{size}	τ_{ci}	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
			1.32	1.94	2.13	2.25	2.46	3.38
36.0	100.0	2.33	No Motion	No Motion	No Motion	No Motion	Motion	Motion
32.0	100.0	2.25	No Motion	No Motion	No Motion	No Motion	Motion	Motion
28.0	100.0	2.16	No Motion	No Motion	No Motion	Motion	Motion	Motion
23.0	100.0	2.04	No Motion	No Motion	Motion	Motion	Motion	Motion
18.0	100.0	1.90	No Motion	Motion	Motion	Motion	Motion	Motion
15.0	100.0	1.79	No Motion	Motion	Motion	Motion	Motion	Motion
12.0	100.0	1.68	No Motion	Motion	Motion	Motion	Motion	Motion
10.0	96.0	1.59	No Motion	Motion	Motion	Motion	Motion	Motion
8.0	83.7	1.49	No Motion	Motion	Motion	Motion	Motion	Motion
6.0	75.5	1.36	No Motion	Motion	Motion	Motion	Motion	Motion
5.0	67.3	1.29	Motion	Motion	Motion	Motion	Motion	Motion
4.0	60.4	1.21	Motion	Motion	Motion	Motion	Motion	Motion
3.0	55.9	1.11	Motion	Motion	Motion	Motion	Motion	Motion
2.5	51.4	1.05	Motion	Motion	Motion	Motion	Motion	Motion
2.0	40.9	0.98	Motion	Motion	Motion	Motion	Motion	Motion
1.5	34.7	0.90	Motion	Motion	Motion	Motion	Motion	Motion
1.0	28.4	0.80	Motion	Motion	Motion	Motion	Motion	Motion
0.8	20.6	0.73	Motion	Motion	Motion	Motion	Motion	Motion
0.5	13.8	0.65	Motion	Motion	Motion	Motion	Motion	Motion
0.2	10.5	0.48	Motion	Motion	Motion	Motion	Motion	Motion
0.017	3.9	0.23	Motion	Motion	Motion	Motion	Motion	Motion
0.003	2.1	0.14	Motion	Motion	Motion	Motion	Motion	Motion

D_{50} =	**2.43**	in	D_{95} =	**9.84**	in
	0.20	ft		0.82	ft
	61.8	mm		249.9	mm



Fuller-Thompson Gradation

Dmax = 12.00

Rock Size [in]	D_{size}
36.0	163.9
32.0	155.5
28.0	146.4
23.0	134.0
18.0	120.0
15.0	110.6
12.0	100.0
10.0	92.1
8.0	83.3
6.0	73.2
5.0	67.4
4.0	61.0
3.0	53.6
2.5	49.4
2.0	44.7
1.5	39.2
1.0	32.7
0.5	23.9
0.2	15.4
0.02	5.2
0.003	2.4

Summary - Stream Simulation Bed Material Design

Project:	**UNT to Puget Sound, SR 308 MP 2.16, WDFW ID 991000**
By:	**David Evans and Associates; Micco Emeson, PE**

Design Gradation				
Location:	Proposed Channel			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.3	0.2	0.1	0.0
in	4.0	2.3	0.8	0.1
mm	102	57	21.0	1.8

Existing Gradation				
Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation				
Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation				
Location:	Existing Average			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.3	0.1	0.1	0.0
in	3.5	1.5	0.8	0.2
mm	90	39	19.8	5.6

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				96.0
2.5	63.5	100	65	54	37	32	28				93.0
2.0	50.8	80	50	45	29	25	22				74.0
1.5	38.1	74	35	34	21	18	16				66.2
1.0	25.4	68	17	23	13	12	11				57.7
0.75	19.1	57	5	5	5	5	5				46.6
0.50	12.7	46									36.8
0.19	4.75	35									28.0
0.017	0.425	13									10.4
0.003	0.075	7									5.6
% per category		80	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*100.0%*
% Cobble & Sediment		80.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

United States Forest Service (USFS)

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E - Methods for Streambed Mobility/Stability Analysis

Range of Suitability:

$D_{84\ ranging}$ between 0.40 in and 10 in

Uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

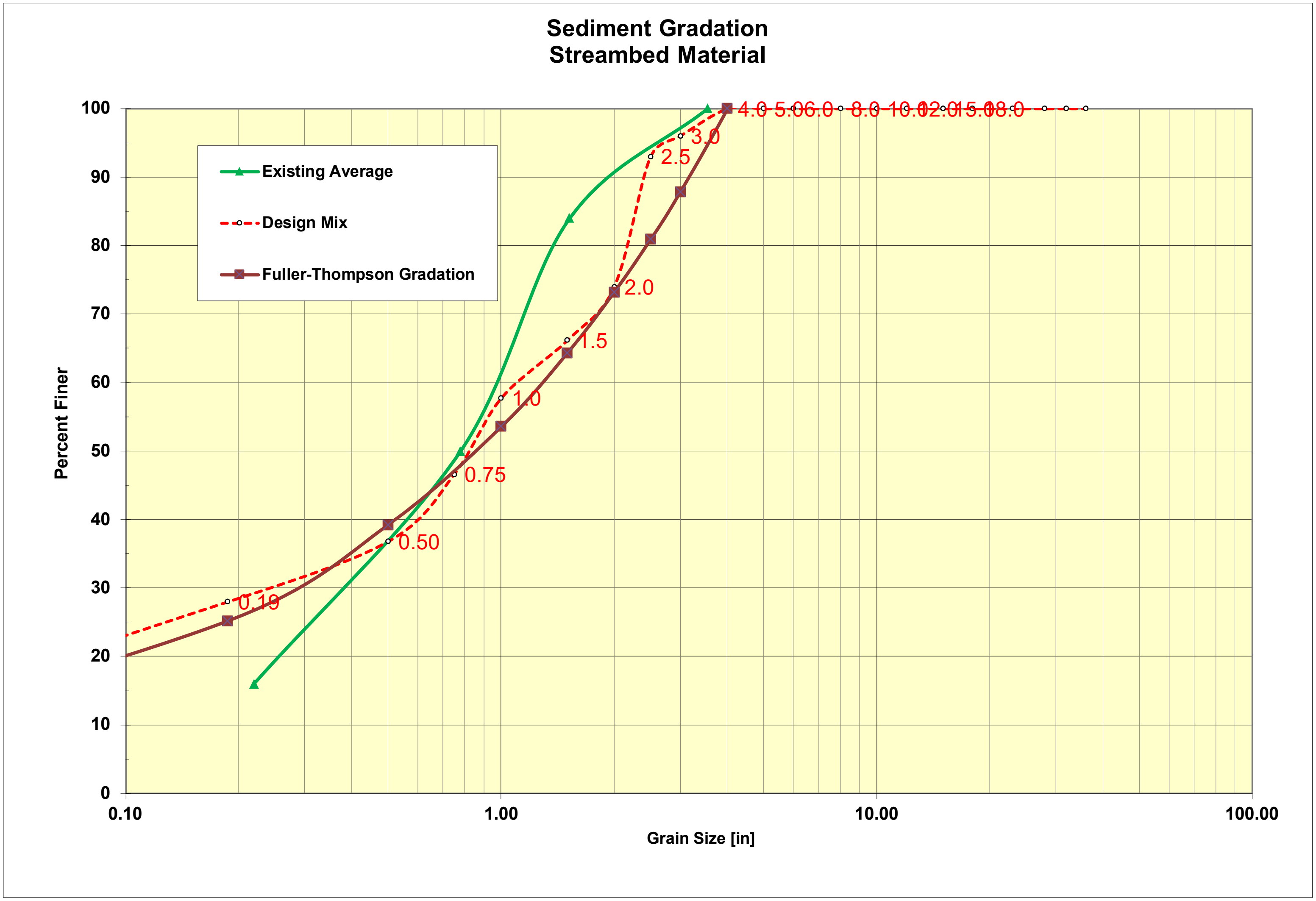
γ_s =	165	specific weight of sediment particle (lb/ft^3)
γ =	62.4	specific weight of water (lb/ft^3)
τ_{D50} =	0.047	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

τ_{ci} = the critical shear stress at which the sediment particle of interest begins to move (lb/ft^2 or N/m^2)

Average Modeled Shear Stress (lb/ft^2)

Rock Size [in]	D_{size}	τ_{ci}	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
			1.32	1.94	2.13	2.25	2.46	3.38
36.0	100.0	1.03	Motion	Motion	Motion	Motion	Motion	Motion
32.0	100.0	0.99	Motion	Motion	Motion	Motion	Motion	Motion
28.0	100.0	0.96	Motion	Motion	Motion	Motion	Motion	Motion
23.0	100.0	0.90	Motion	Motion	Motion	Motion	Motion	Motion
18.0	100.0	0.84	Motion	Motion	Motion	Motion	Motion	Motion
15.0	100.0	0.79	Motion	Motion	Motion	Motion	Motion	Motion
12.0	100.0	0.74	Motion	Motion	Motion	Motion	Motion	Motion
10.0	100.0	0.70	Motion	Motion	Motion	Motion	Motion	Motion
8.0	100.0	0.66	Motion	Motion	Motion	Motion	Motion	Motion
6.0	100.0	0.60	Motion	Motion	Motion	Motion	Motion	Motion
5.0	100.0	0.57	Motion	Motion	Motion	Motion	Motion	Motion
4.0	100.0	0.53	Motion	Motion	Motion	Motion	Motion	Motion
3.0	96.0	0.49	Motion	Motion	Motion	Motion	Motion	Motion
2.5	93.0	0.46	Motion	Motion	Motion	Motion	Motion	Motion
2.0	74.0	0.43	Motion	Motion	Motion	Motion	Motion	Motion
1.5	66.2	0.40	Motion	Motion	Motion	Motion	Motion	Motion
1.0	57.7	0.35	Motion	Motion	Motion	Motion	Motion	Motion
0.8	46.6	0.32	Motion	Motion	Motion	Motion	Motion	Motion
0.5	36.8	0.29	Motion	Motion	Motion	Motion	Motion	Motion
0.2	28.0	0.21	Motion	Motion	Motion	Motion	Motion	Motion
0.017	10.4	0.10	Motion	Motion	Motion	Motion	Motion	Motion
0.003	5.6	0.06	Motion	Motion	Motion	Motion	Motion	Motion

D_{50} =	**0.83**	in	D_{95} =	**2.83**	in
	0.07	ft		0.24	ft
	21.0	mm		72.0	mm

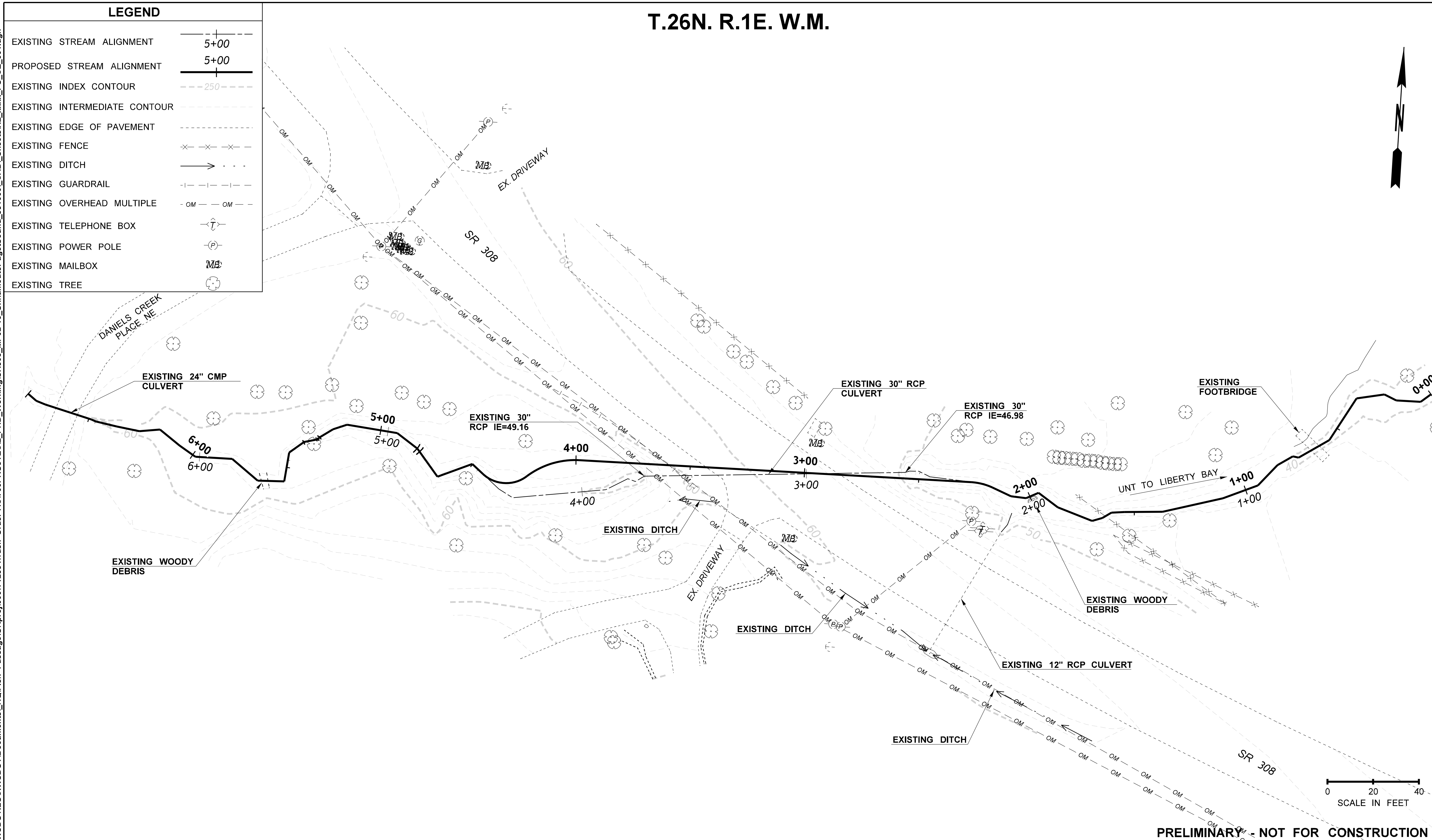


Fuller-Thompson Gradation

Dmax = 4.00

Rock Size [in]	D_{size}
36.0	268.8
32.0	254.9
28.0	240.0
23.0	219.7
18.0	196.8
15.0	181.3
12.0	163.9
10.0	151.0
8.0	136.6
6.0	120.0
5.0	110.6
4.0	100.0
3.0	87.9
2.5	80.9
2.0	73.2
1.5	64.3
1.0	53.6
0.5	39.2
0.2	25.2
0.02	8.5
0.003	3.9

Appendix D: Stream Plan Sheets, Profile, Details



PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	11/2/2022			
PLOTTED BY	Mike Keilbart			
DESIGNED BY	M. EMESON			
ENTERED BY	M. KEILBART			
CHECKED BY	K. COMINGS			
PROJ. ENGR.	J. HEILMAN			
REGIONAL ADM.		REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

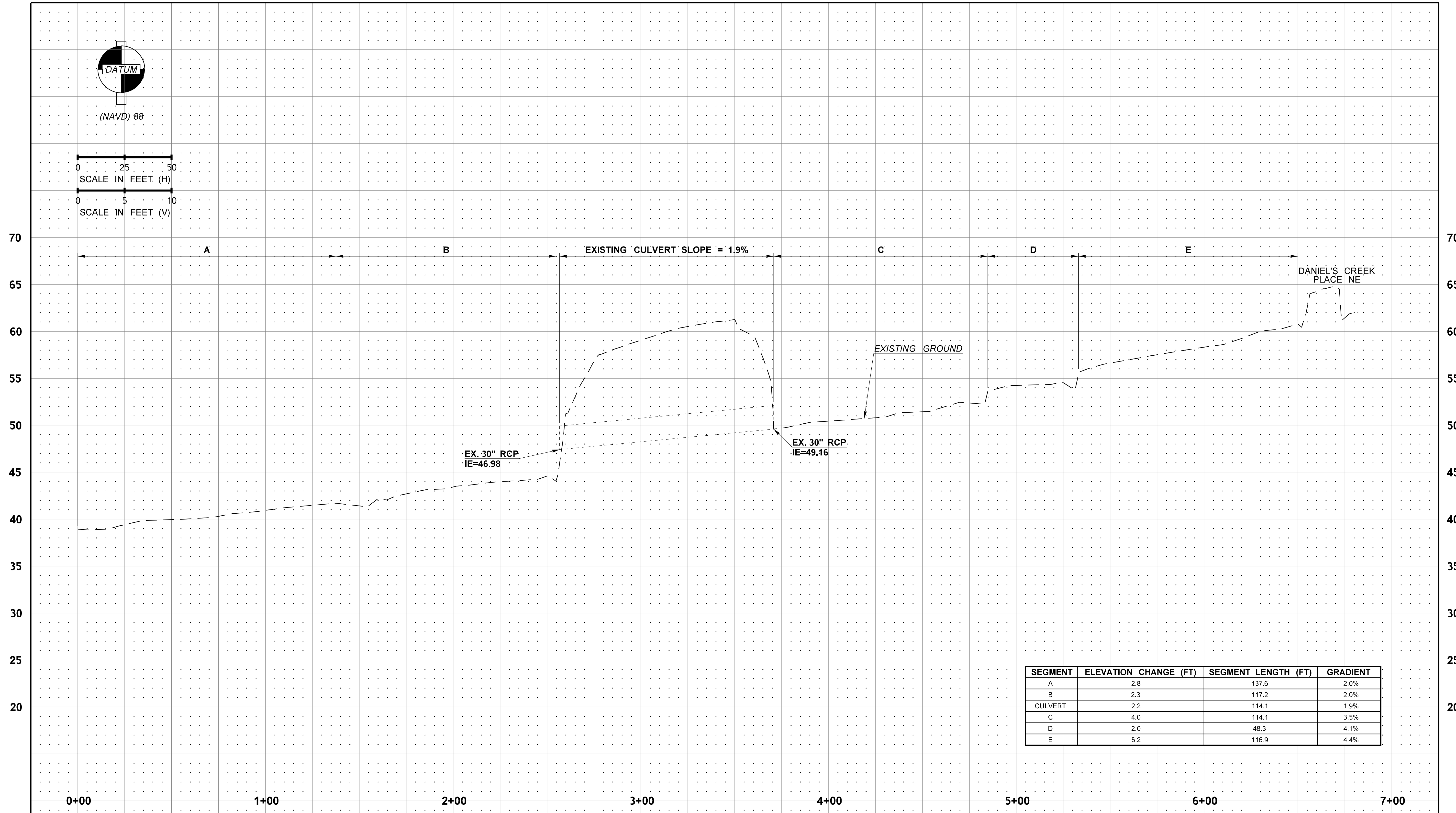
SR 308 MP 02.16
UNT TO LIBERTY BAY
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 5 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR308_MP02-16_UnnamedtoPugetSound_991000_CAD_Sheets\XL_xxxx_PS_CE_001.dgn



SEGMENT	ELEVATION CHANGE (FT)	SEGMENT LENGTH (FT)	GRADIENT
A	2.8	137.6	2.0%
B	2.3	117.2	2.0%
CULVERT	2.2	114.1	1.9%
C	4.0	114.1	3.5%
D	2.0	48.3	4.1%
E	5.2	116.9	4.4%

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	11/2/2022
PLOTTED BY	Mike Keilbart
DESIGNED BY	M. EMESON
ENTERED BY	M. KEILBART
CHECKED BY	K. COMINGS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER: XXXXX

CONTRACT NO.

LOCATION NO.: XL_____

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

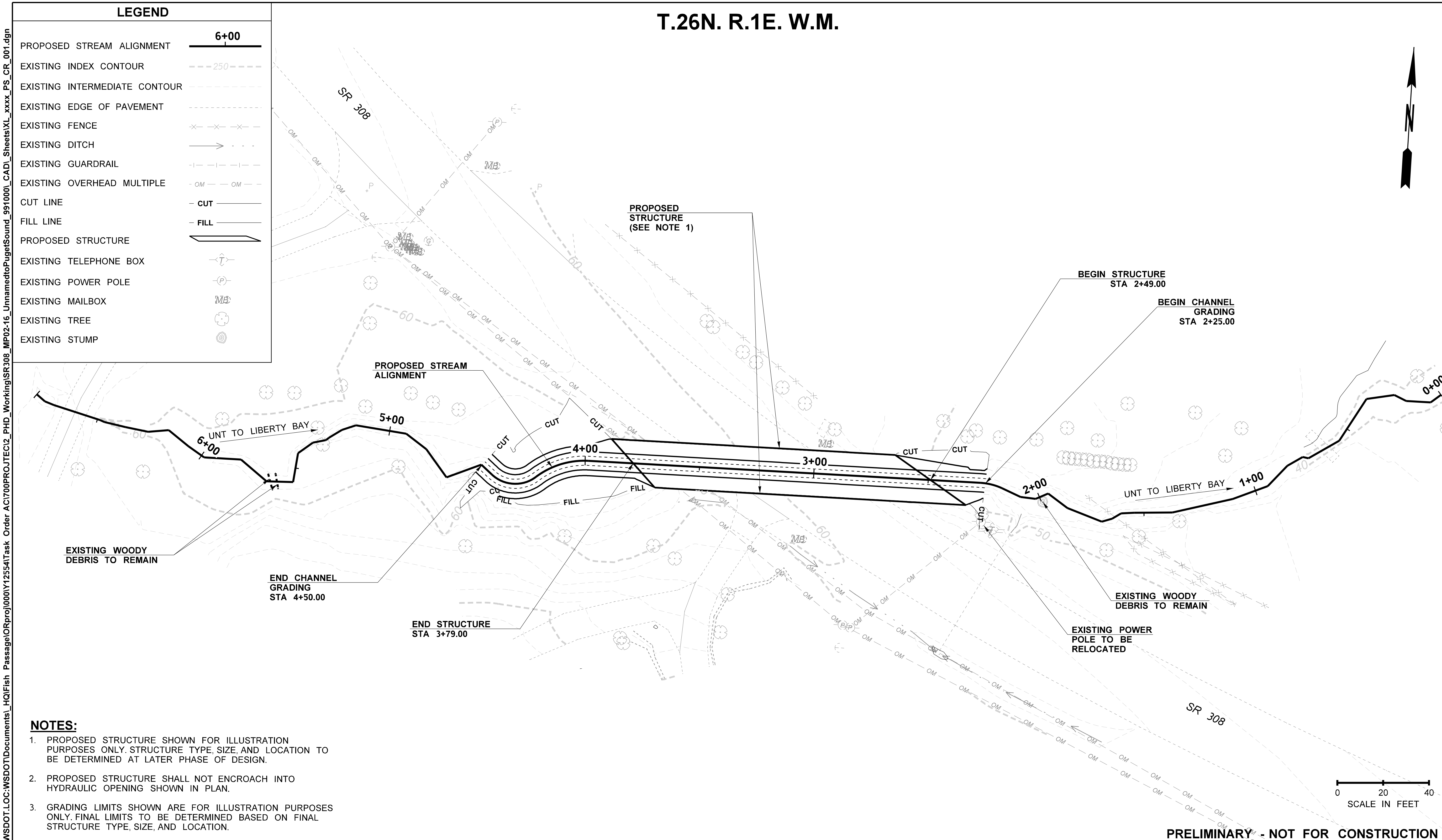
Washington State Department of Transportation

SR 308 MP 02.16
UNT TO LIBERTY BAY
FISH BARRIER REMOVAL

EXISTING STREAM PROFILE

PLAN REF. NO. CP1

SHEET 2 OF 5 SHEETS



NOTES:

1. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATION PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED AT LATER PHASE OF DESIGN.
2. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN IN PLAN.
3. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	11/2/2022
PLOTTED BY	Mike Keilbart
DESIGNED BY	M. EMESON
ENTERED BY	M. KEILBART
CHECKED BY	K. COMINGS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 308 MP 02.16
UNT TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM PLAN

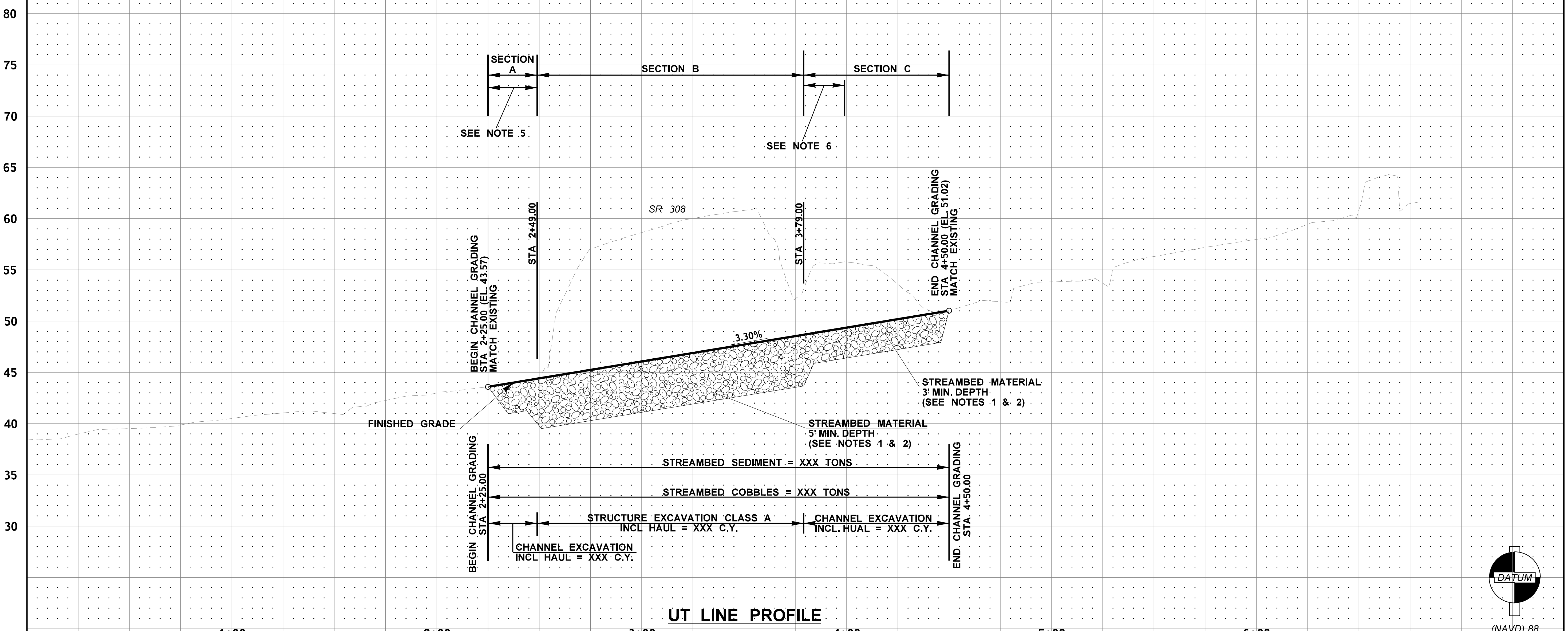
PLAN REF NO CR1

SHEET 3 OF 5 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR308_MP02-16_UnnamedtoPugetSound_991000_CAD_Sheets\XL_xxxx_PS_CR_001.dgn

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIALS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS
3. SEE SHEET CD1 FOR STREAM SECTIONS.
4. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.
5. FROM STA 2+25 TO STA 2+49 EVENLY TAPER SECTION A TO MATCH SECTION B.
6. FROM STA 3+79 TO STA 3+99 EVENLY TAPER SECTION B TO MATCH SECTION C.



UT LINE PROFILE

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	3/16/2023				
PLOTTED BY	Mike Keilbart				
DESIGNED BY	M. EMESON				
ENTERED BY	M. KEILBART				
CHECKED BY	K. COMINGS				
PROJ. ENGR.	J. HEILMAN				
REGIONAL ADM.		REVISION	DATE	BY	

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 308 MP 02.16
UNT TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM PROFILE

PLAN REF. NO. CP2

SHEET 4 OF 5 SHEETS

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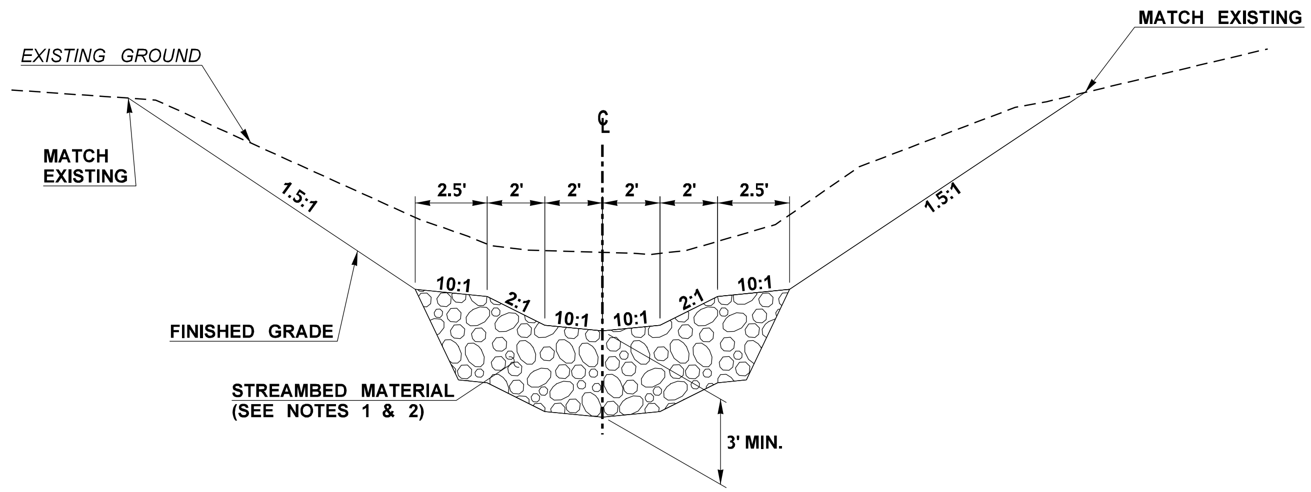
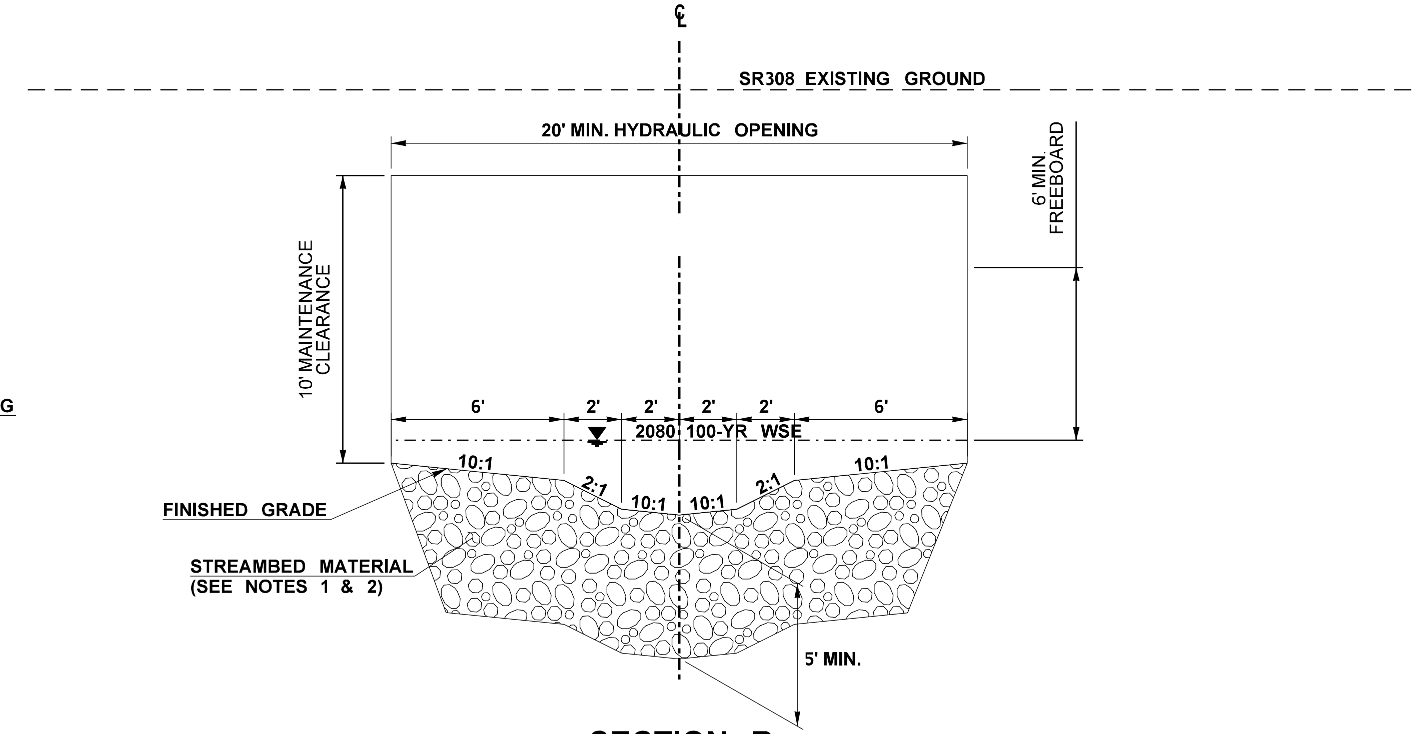


SECTION A

STATION 2+25.00 TO 2+49.00

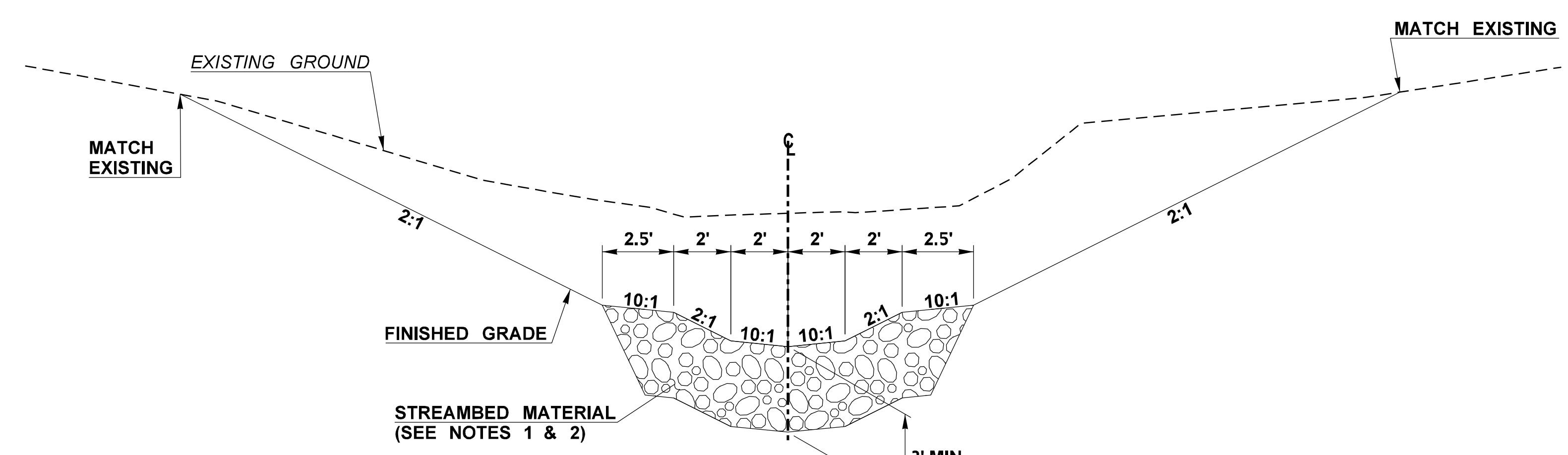


SECTION B

STATION 2+49.00 TO 3+79.00

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIALS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS
3. SEE SHEET CD1 FOR STREAM SECTIONS.
4. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATION PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED AT LATER PHASE OF DESIGN.
5. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN IN PLAN.
6. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.
7. SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
8. FROM STA 2+25.00 TO STA 2+35.00, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
9. FROM STA 4+40.00 TO STA 4+50.00, EVENLY TAPER SECTION C TO MATCH EXISTING CHANNEL.
10. FROM STA 2+25 TO STA 2+49 EVENLY TAPER SECTION A TO MATCH SECTION B.
11. FROM STA 3+79 TO STA 3+99 EVENLY TAPER SECTION B TO MATCH SECTION C.



SECTION C

STATION 3+79.00 TO 4+50.00

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	3/16/2023
PLOTTED BY	Mike Keilbart
DESIGNED BY	M. EMESON
ENTERED BY	M. KEILBART
CHECKED BY	K. COMINGS
PROJ. ENGR.	J. HEILMAN
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State
Department of Transportation

SR 308 MP 02.16
UNT TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM DETAILS

PLAN REF NO CD1

SHEET 5 OF 5 SHEETS

Appendix E: Manning's Calculations (NOT USED)

Appendix F: Large Woody Material Calculations

Culvert Configuration

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 308 MP 2.16*	**Key piece volume**	***1.310***	*yd3*	
Stream name	*UNT to Liberty Bay*	**Key piece/ft**	***0.0335***	*per ft stream*	
length of regrade[a]	*225 ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*	Taper coeff. -0.01554
Bankfull width	*7.5 ft*	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*	LF_{rw} 1.5
Habitat zone[b]	*Western WA*				H_{dbh} 4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)*[d]	*Volume (yd^3/log)*[d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)	$D_{root\ collar}$ (ft)	L/2-Lrw (ft)
A	2.00	*30*	3.49	**yes**	yes	4	13.96	2.12	2.19	12
B	1.50	*25*	1.64	**yes**	yes	4	6.54	1.59	1.66	10.25
C	1.00	*20*	0.58	**yes**	no	8	4.65	1.06	1.13	8.5
D	0.5	*10*	0.07	**no**	no	10	0.73	0.58	0.57	4.25
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	8	26	25.9
Targets	**8**	**26**	**88.8**
	on target	on target	deficit

[a] **includes length through crossing, regardless of structure type**

[b] **choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information**

Western Washington lowl:	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine	(mainly east slope Cascades below 3,700 ft. elevation)

[c]**LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).**

[d]**includes rootwad if present**

Bridge Configuration

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***SR 308 MP 2.16***	**Key piece volume**	***1.310***	*yd3*	
Stream name	*UNT to Liberty Bay*	**Key piece/ft**	***0.0335***	*per ft stream*	
length of regrade[a]	*225 ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*	Taper coeff. -0.01554
Bankfull width	*7.5 ft*	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*	LF_{rw} 1.5
Habitat zone[b]	*Western WA*				H_{dbh} 4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)* [d]	*Volume (yd^3/log)* [d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)	$D_{root\ collar}$ (ft)	L/2-Lrw (ft)
A	2.00	*30*	3.49	**yes**	yes	6	20.94	2.12	2.19	12
B	1.50	*25*	1.64	**yes**	yes	10	16.36	1.59	1.66	10.25
C	1.00	*20*	0.58	**yes**	no	19	11.05	1.06	1.13	8.5
D	0.5	*10*	0.07	**no**	no	17	1.24	0.58	0.57	4.25
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	16	52	49.6
Targets	**8**	**26**	**88.8**
	surplus	surplus	deficit

[a] **includes length through crossing, regardless of structure type**

[b] **choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information**

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

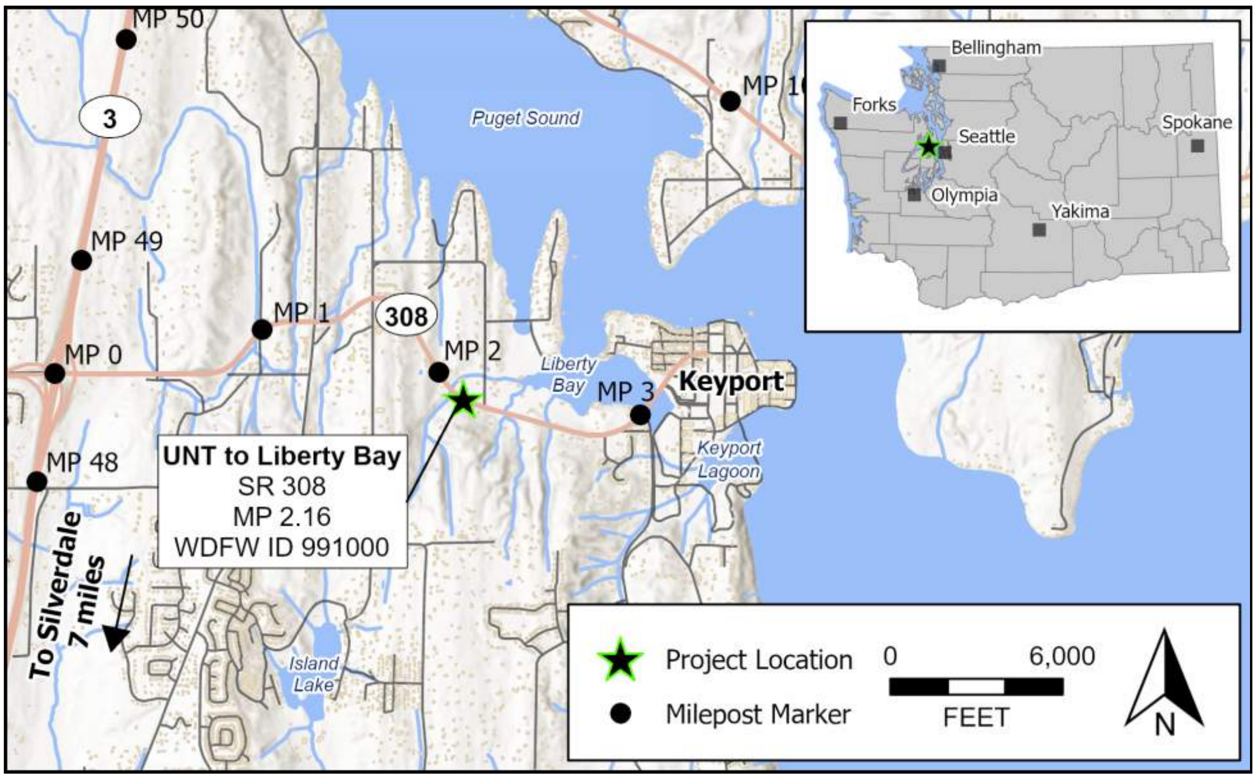
[c] **LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).**

[d] **includes rootwad if present**

Appendix G: Future Projections for Climate-Adapted Culvert Design

2080 100-year Climate Change Projection

The WDFW Climate Change Projection website does not contain predictions for the project site under consideration. Consequently, nearby basins were queried to find a comparable projection within the same region. Island Lake is approximately 1 mile southwest of the project site under consideration (see the Vicinity Map below). Therefore, this analysis used the climate change projections for the Island Lake basin to predict the 2080 100-year peak flows at the culvert 991000 crossing of SR 308 at milepost 2.16.



Vicinity Map

Future Projections for Climate-Adapted Culvert Design

Project Name: SR 308 MP 2.16, WDFW ID 991000

Stream Name: UNT to Liberty Bay

Drainage Area: 348 ac

Projected mean percent change in bankfull flow:

2040s: 13.2%

2080s: 17.4%

Projected mean percent change in bankfull width:

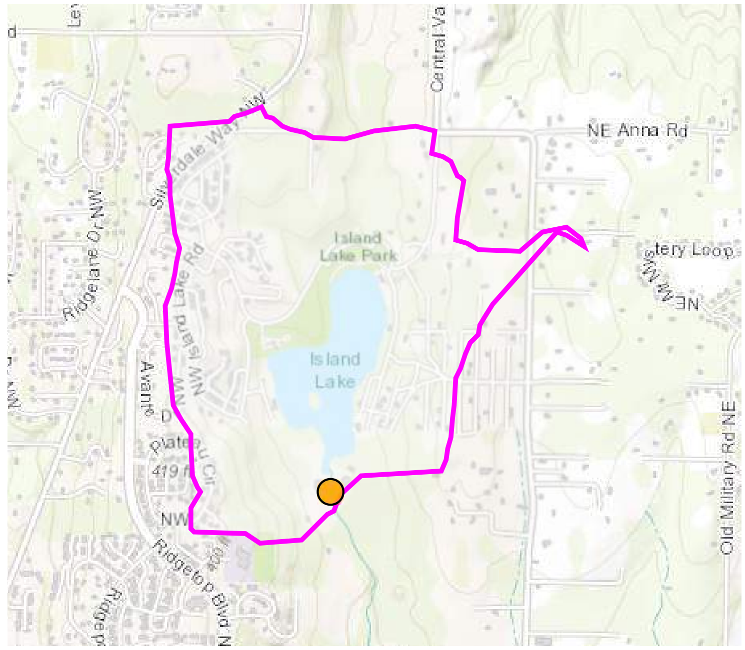
2040s: 6.4%

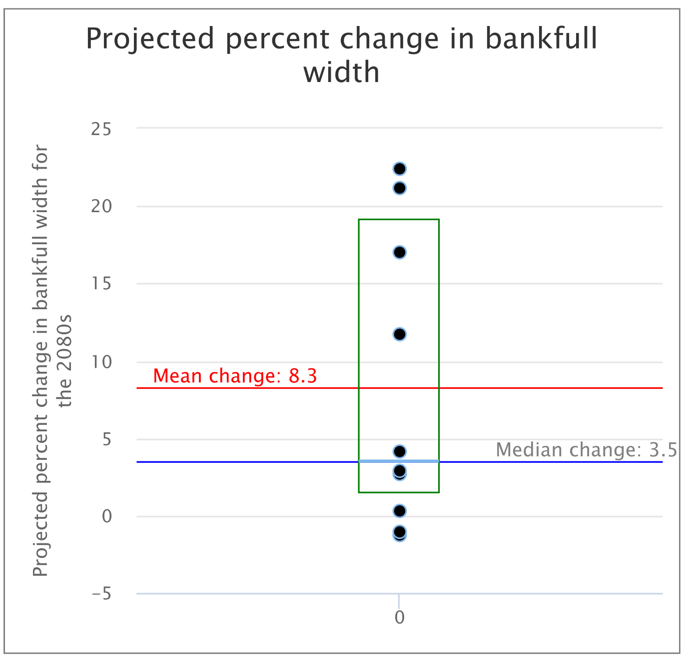
2080s: 8.3%

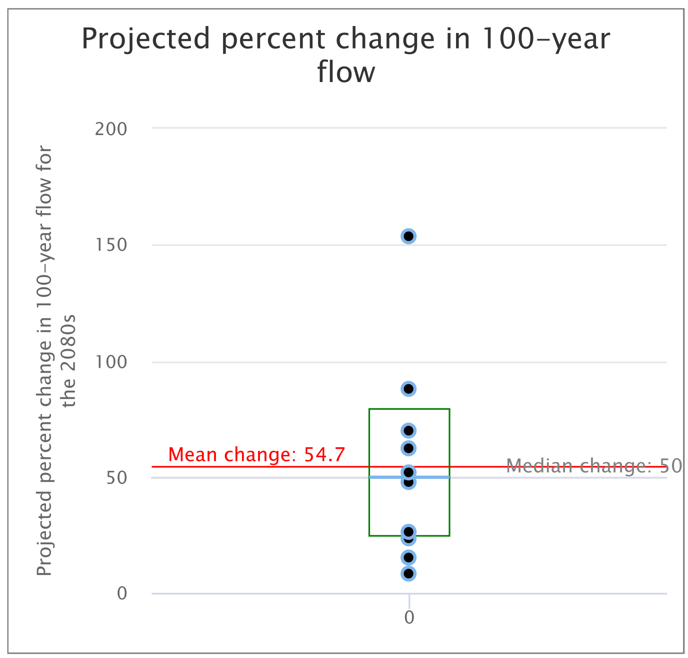
Projected mean percent change in 100-year flood:

2040s: 40.2%

2080s: 54.7%







Black dots are projections from 10 separate models

Appendix H: SRH-2D Model Results

Existing Conditions SRH-2D Results

Planview

Figure H.1: Existing conditions 2-year depth

Figure H.2: Existing conditions 2-year shear

Figure H.3: Existing conditions 2-year velocity

Figure H.4: Existing conditions 2-year WSE

Figure H.5: Existing conditions 100-year depth

Figure H.6: Existing conditions 100-year shear

Figure H.7: Existing conditions 100-year velocity

Figure H.8: Existing conditions 100-year WSE

Figure H.9: Existing conditions 500-year depth

Figure H.10: Existing conditions 500-year shear

Figure H.11: Existing conditions 500-year velocity

Figure H.12: Existing conditions 500-year WSE

Existing Conditions SRH-2D Results

Water Surface Profile

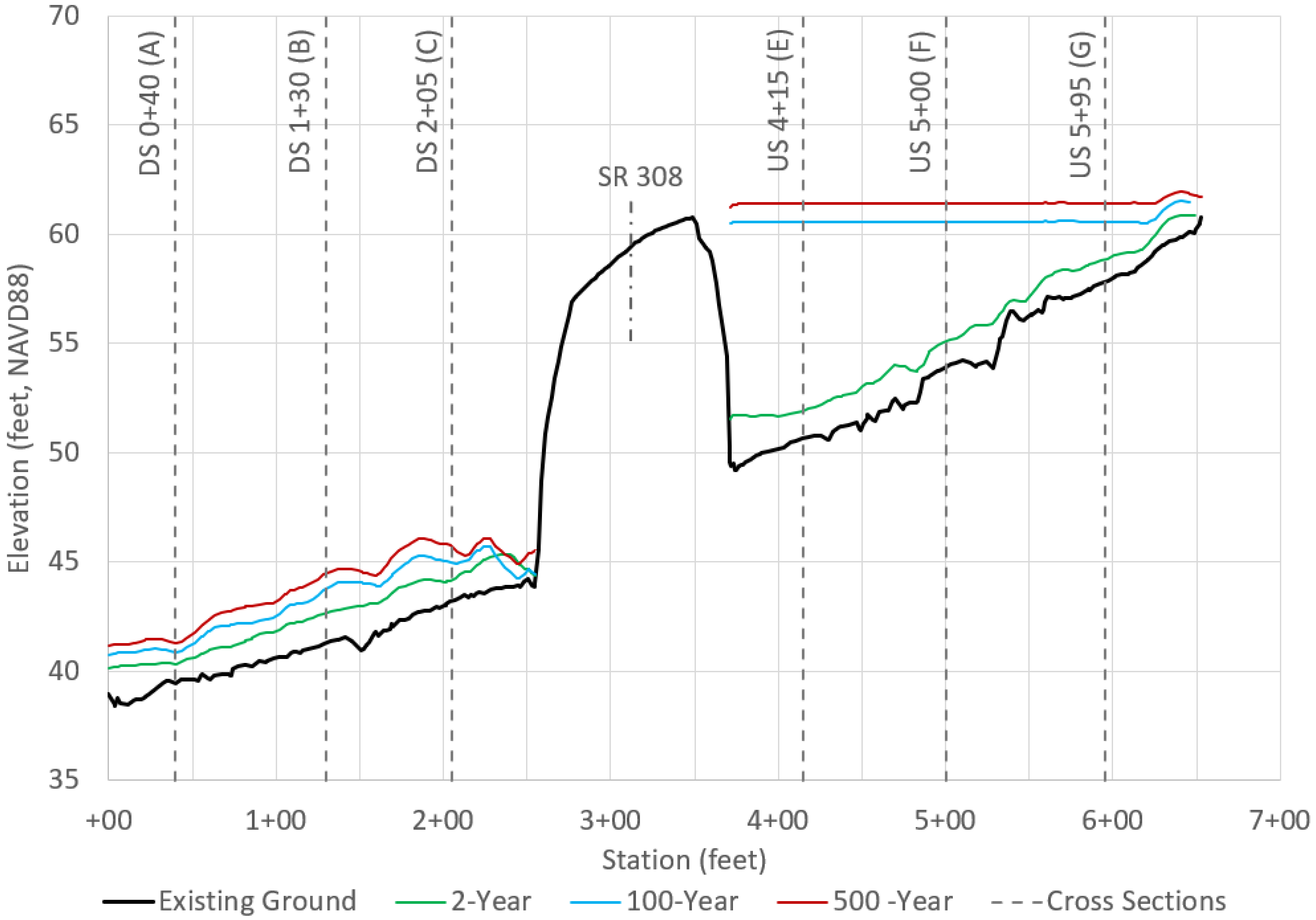


Figure H.13: Existing conditions water surface elevation profile

Existing Conditions SRH-2D Results

Cross Sections

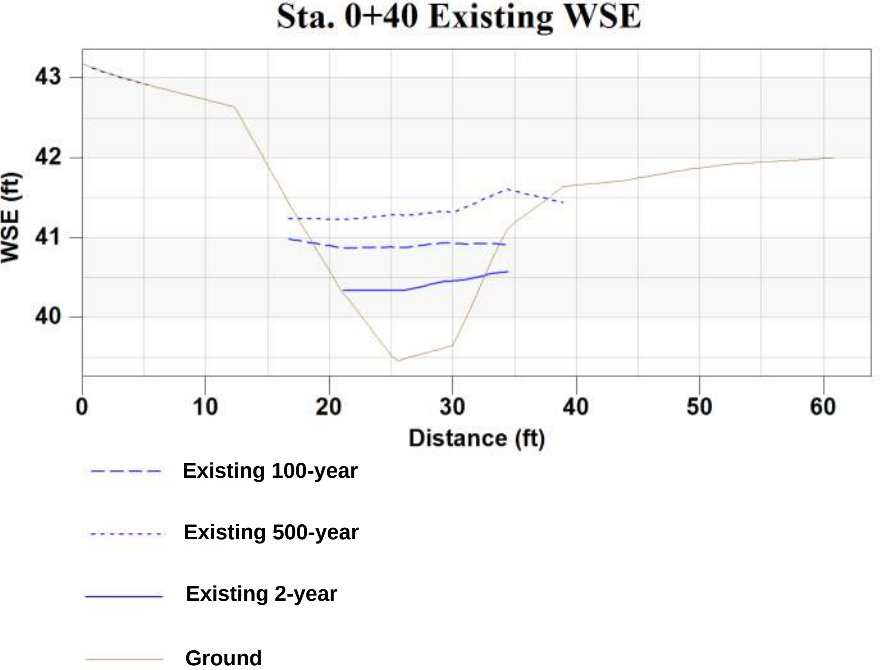


Figure H.14: Existing conditions water surface elevation STA 0+40

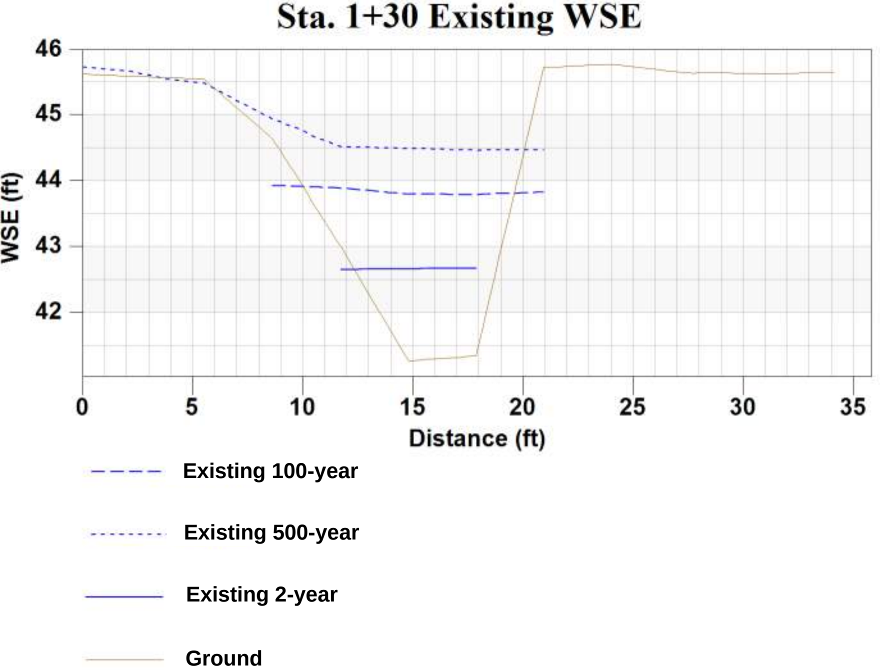


Figure H.15: Existing conditions water surface elevation STA 1+30

Figure H.16: Existing conditions water surface elevation STA 2+05

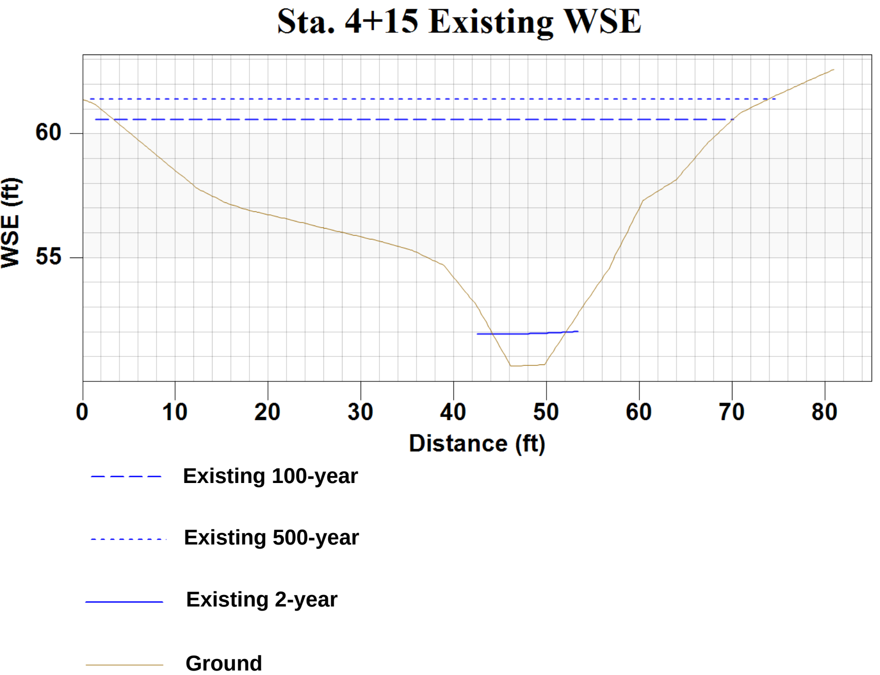


Figure H.17: Existing conditions water surface elevation STA 4+15

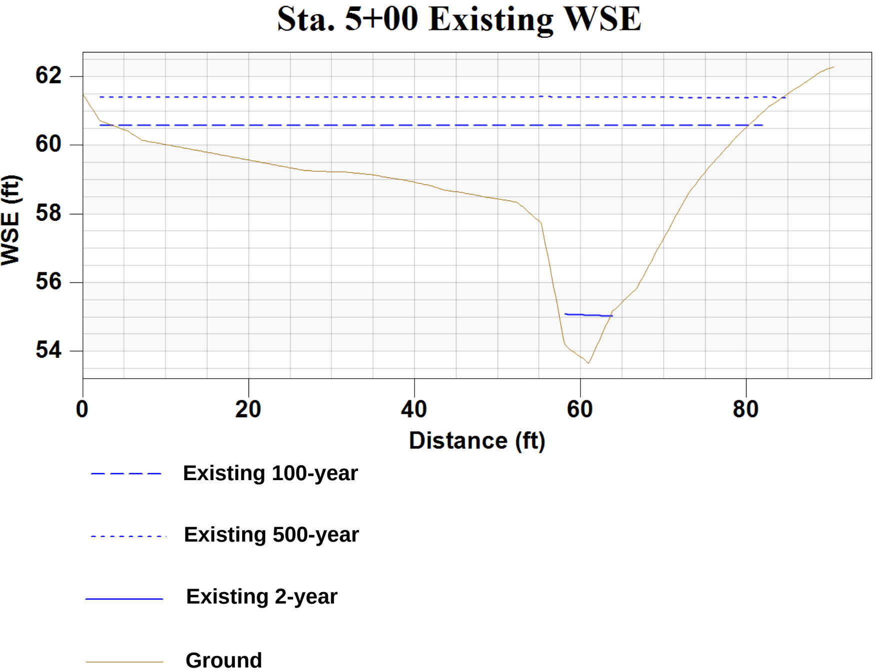


Figure H.18: Existing conditions water surface elevation STA 5+00

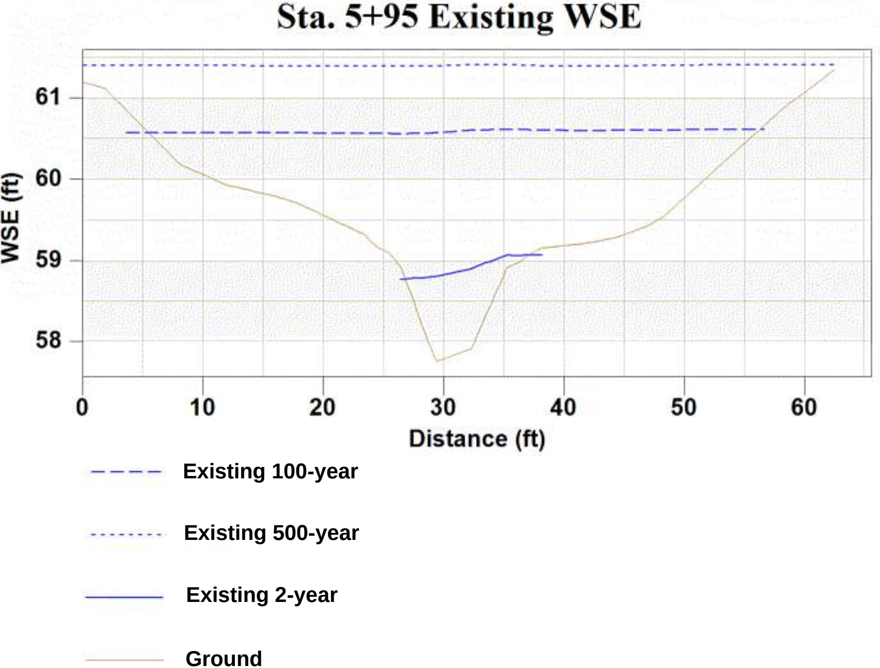


Figure H.19: Existing conditions water surface elevation STA 5+95

Proposed Conditions SRH-2D Results

Planview

Figure H.20: Proposed conditions 2-year depth

Figure H.21: Proposed conditions 2-year shear

Figure H.22: Proposed conditions 2-year velocity

Figure H.23: Proposed conditions 2-year WSE

Figure H.24: Proposed conditions 100-year depth

Figure H.25: Proposed conditions 100-year shear

Figure H.26: Proposed conditions 100-year velocity

Figure H.27: Proposed conditions 100-year WSE

Figure H.28: Proposed conditions 500-year depth

Figure H.29: Proposed conditions 500-year shear

Figure H.30: Proposed conditions 500-year velocity

Figure H.31: Proposed conditions 500-year WSE

Figure H.32: Proposed conditions 2080 100-year depth

Figure H.33: Proposed conditions 2080 100-year shear

Figure H.34: Proposed conditions 2080 100-year velocity

Figure H.35: Proposed conditions 2080 100-year WSE

Proposed Conditions SRH-2D Results

Water Surface Profile

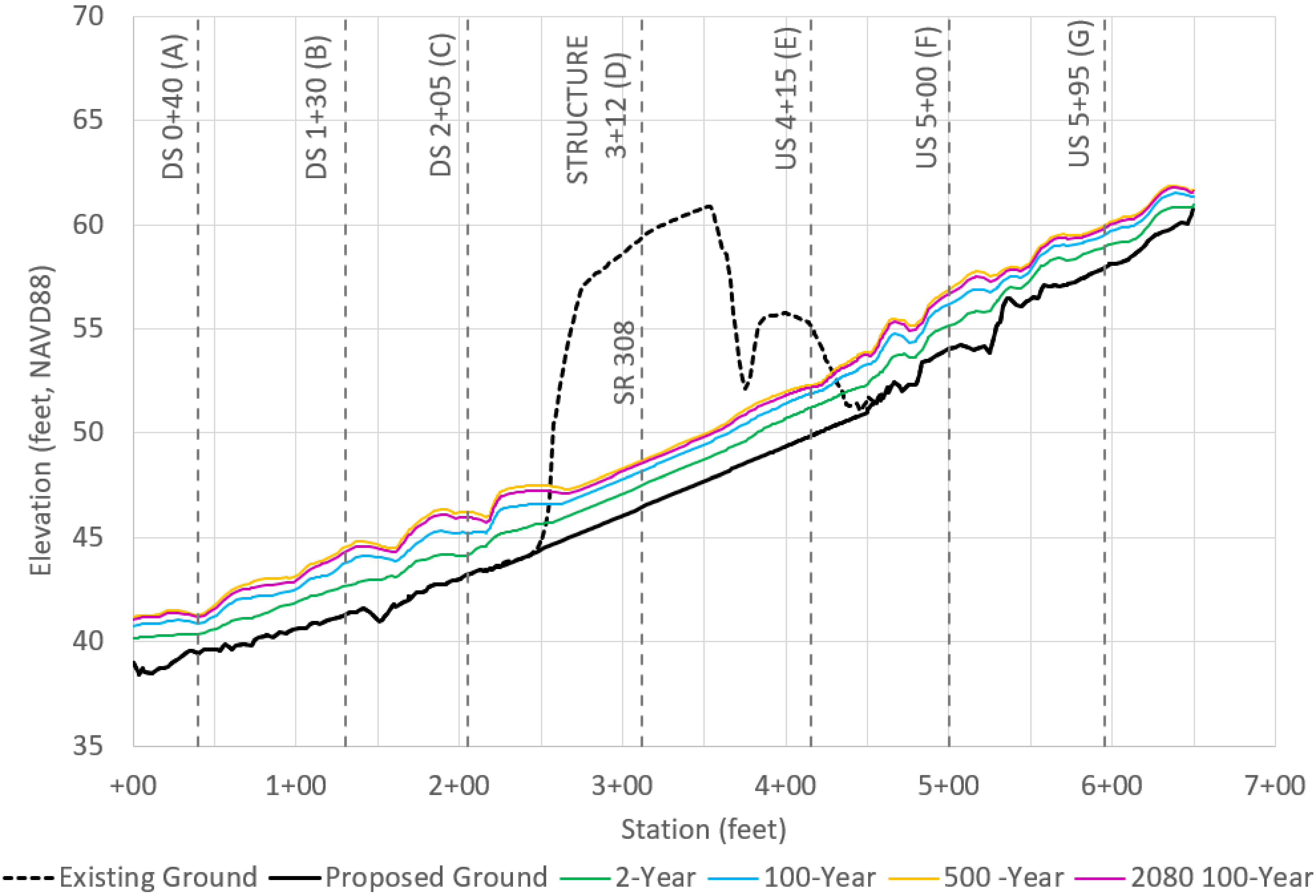


Figure H.36: Proposed conditions water surface elevation profile

Proposed Conditions SRH-2D Results

Cross Sections

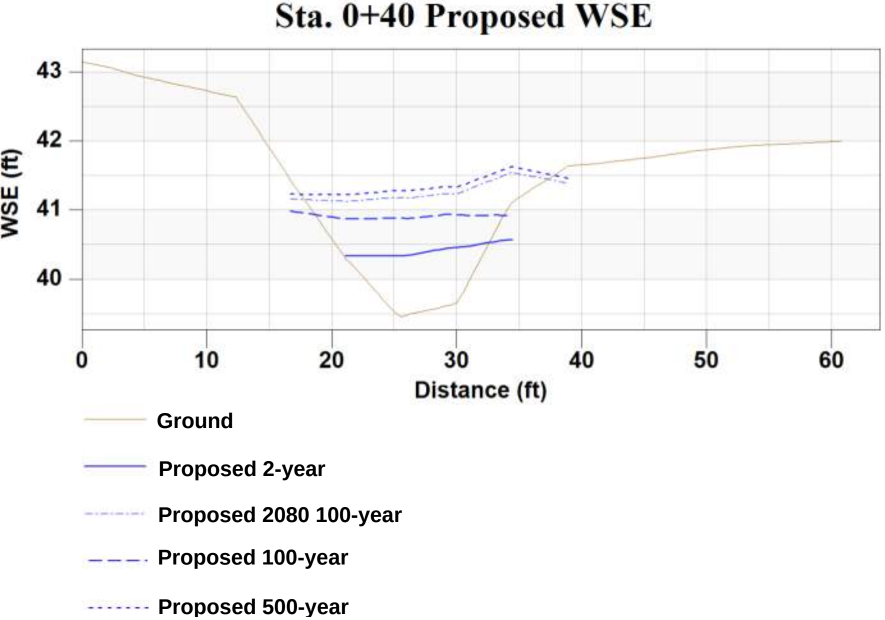


Figure H.37: Proposed conditions water surface elevation STA 0+40

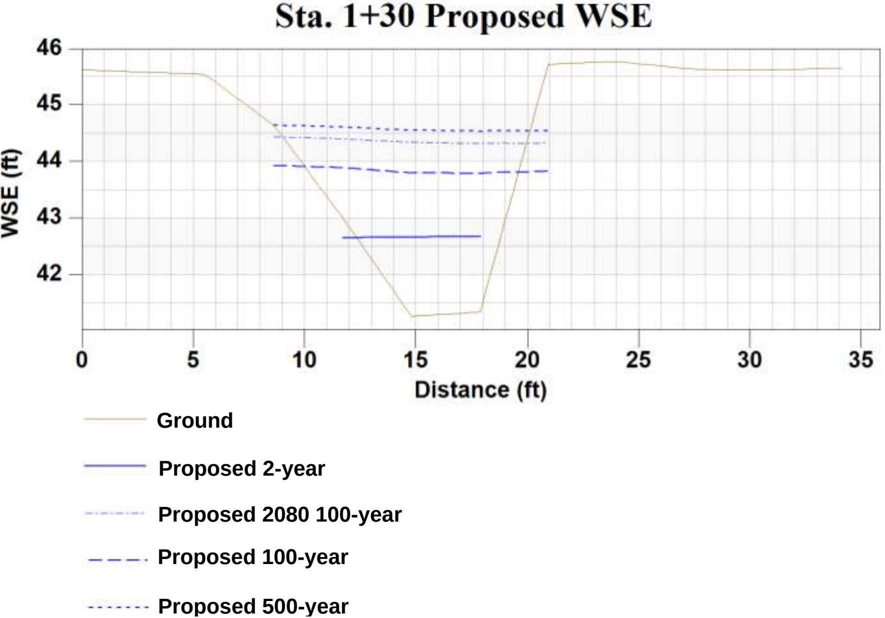


Figure H.38: Proposed conditions water surface elevation STA 1+30

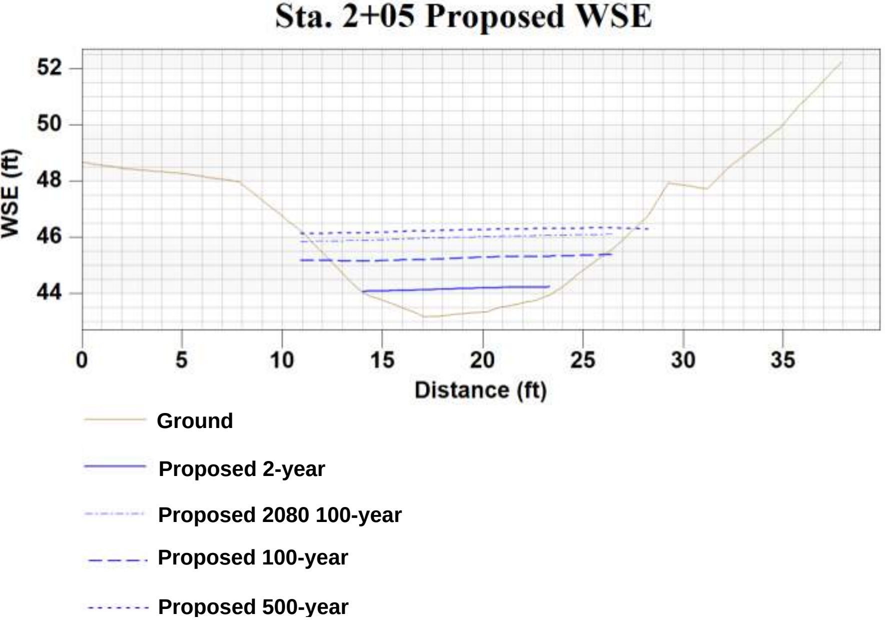


Figure H.39: Proposed conditions water surface elevation STA 2+05

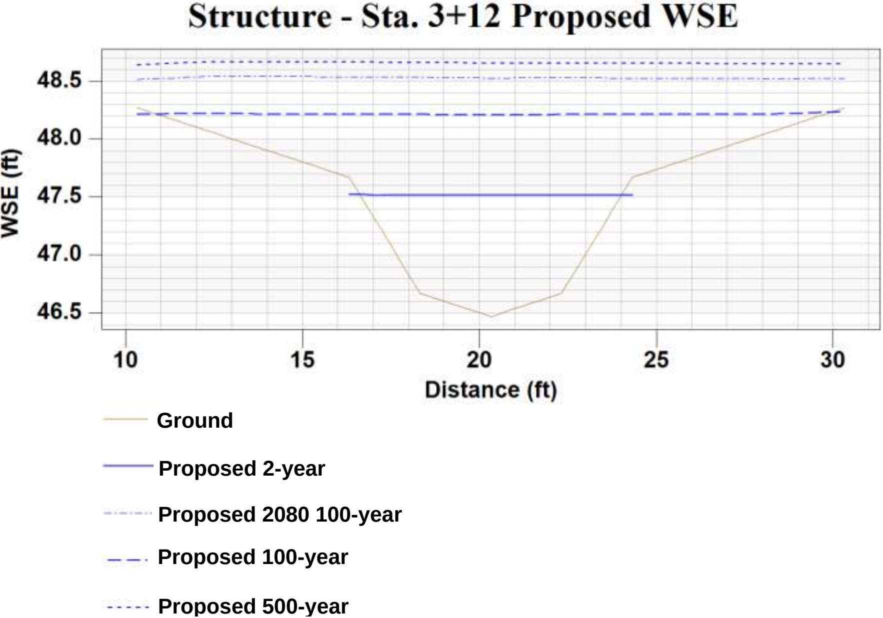


Figure H.40: Proposed conditions water surface elevation STA 3+12

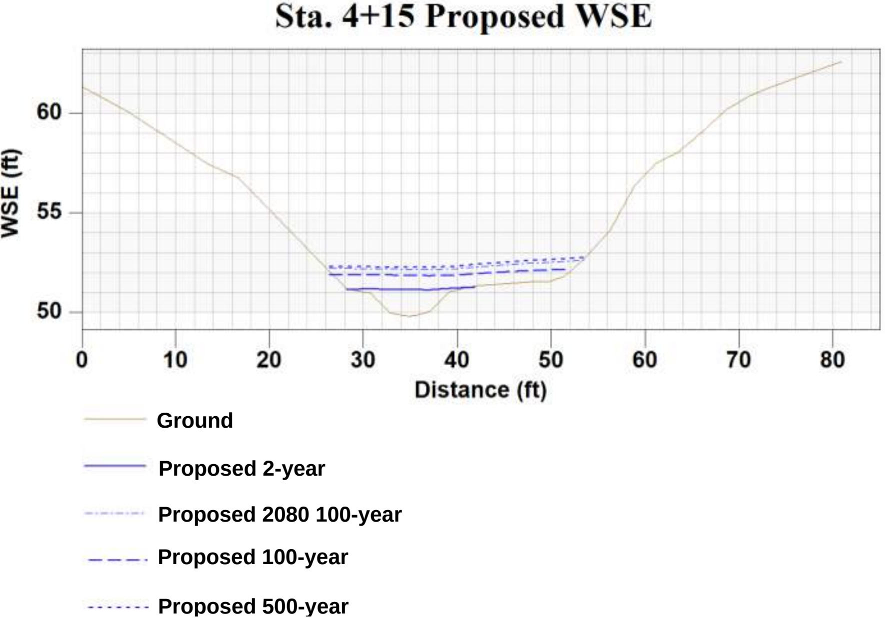


Figure H.41: Proposed conditions water surface elevation STA 4+15

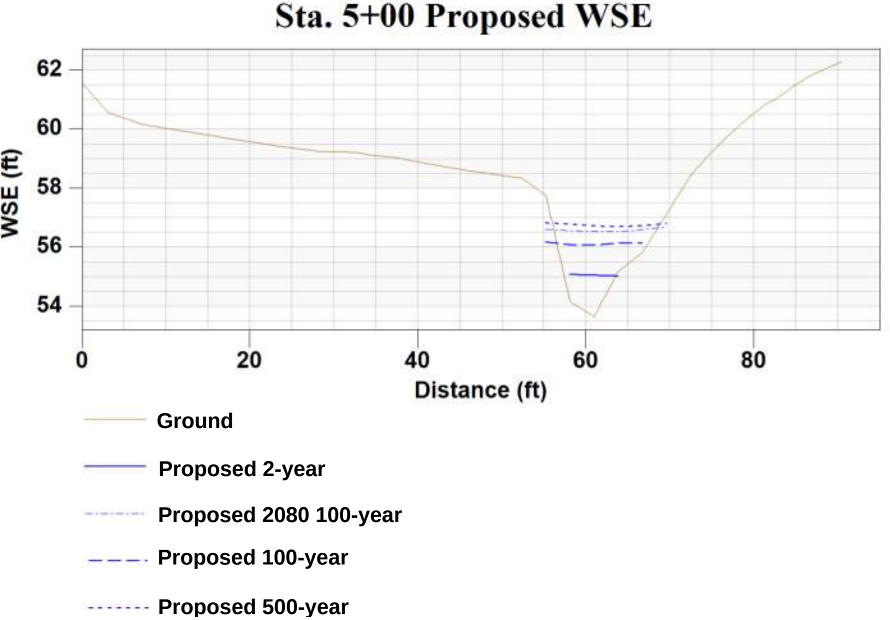


Figure H.42: Proposed conditions water surface elevation STA 5+00

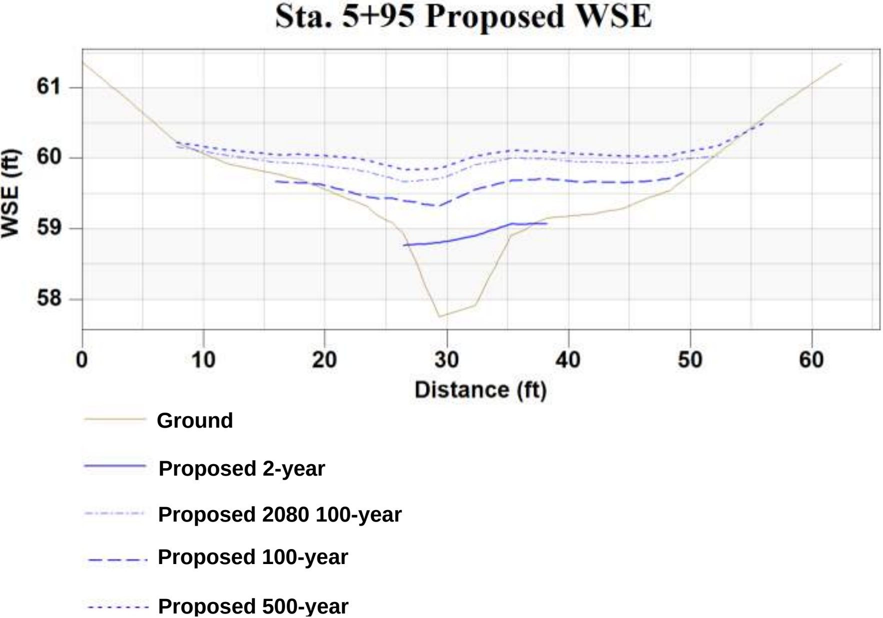


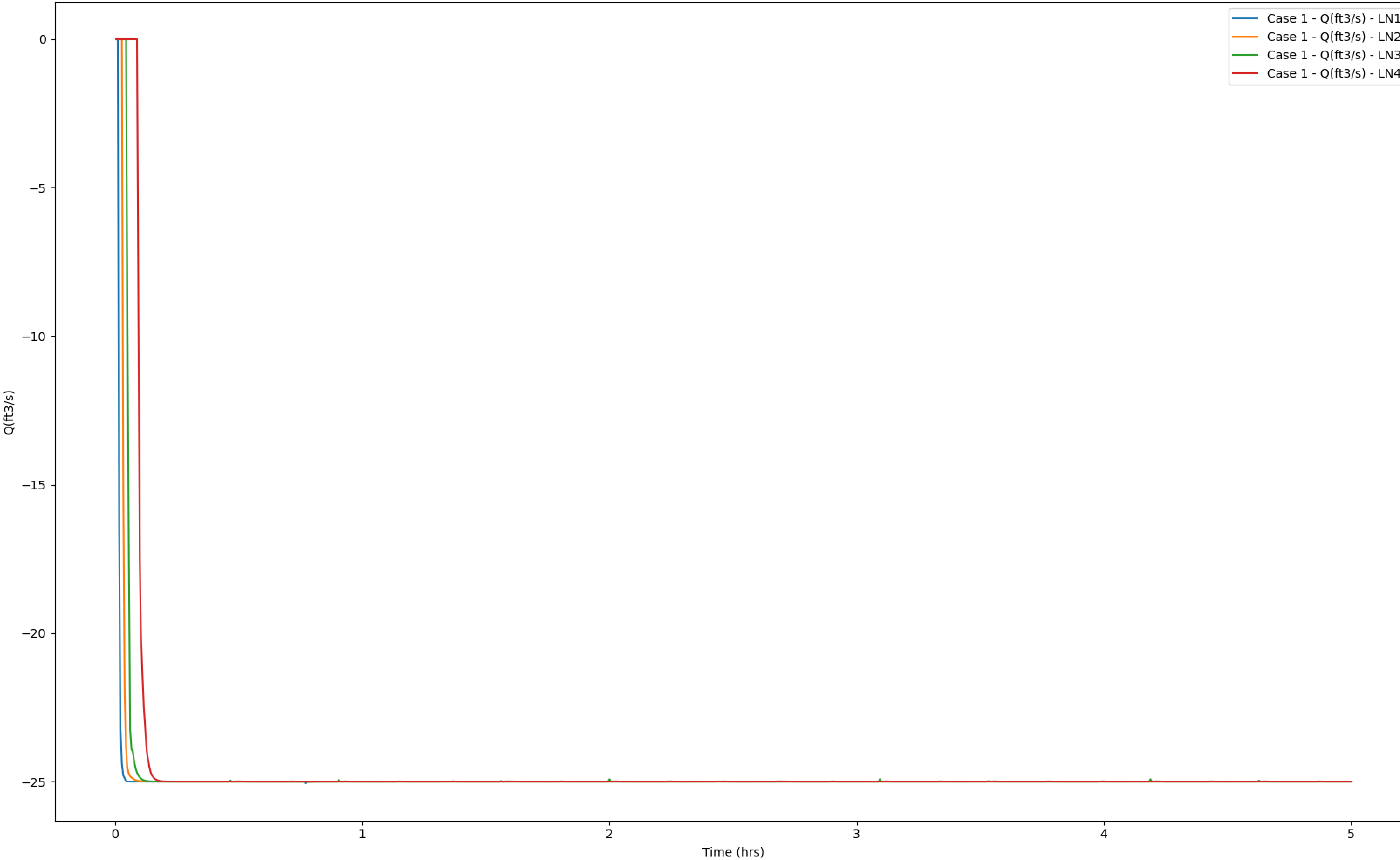
Figure H.43: Proposed conditions water surface elevation STA 5+95

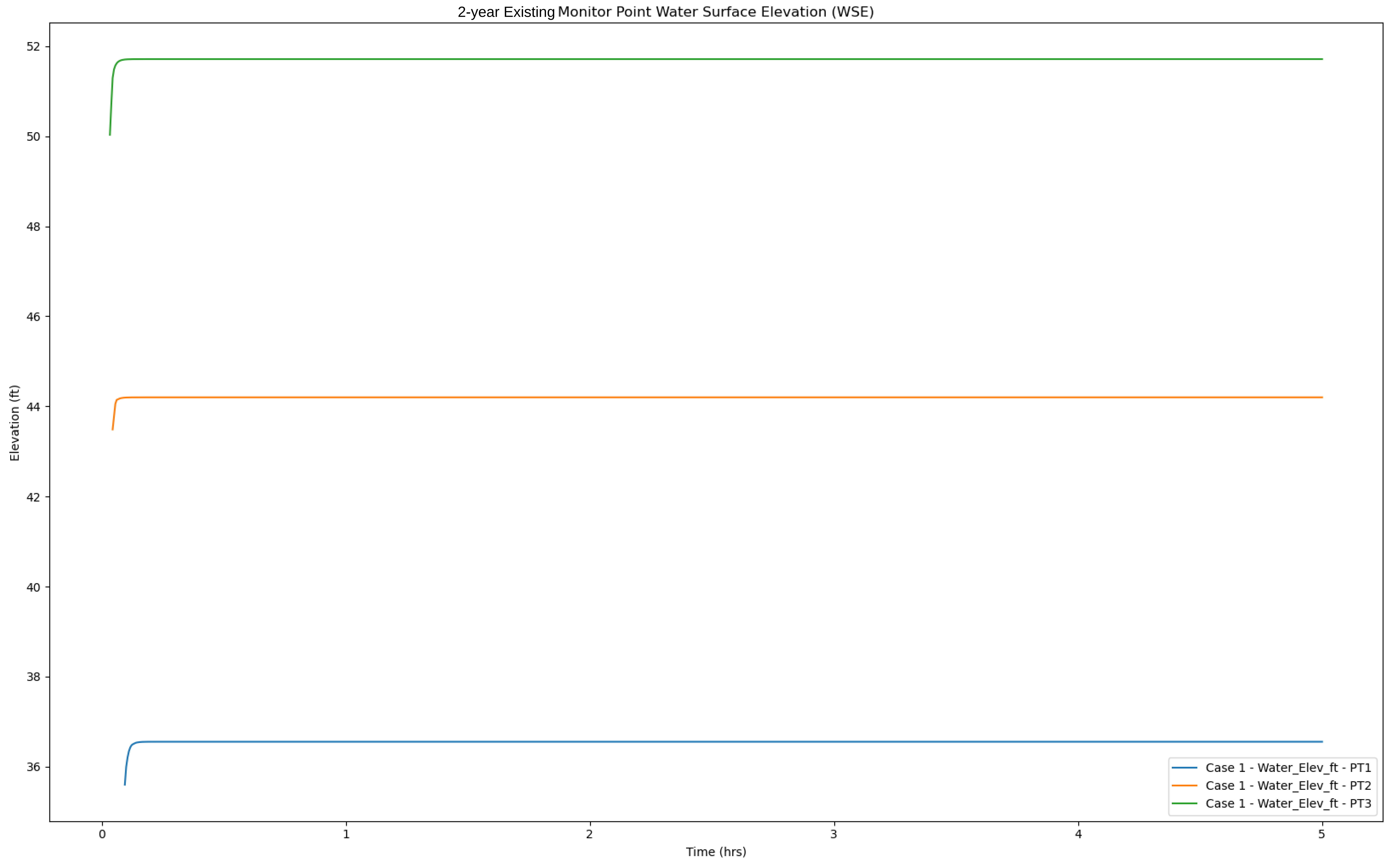
Appendix I: SRH-2D Model Stability and Continuity

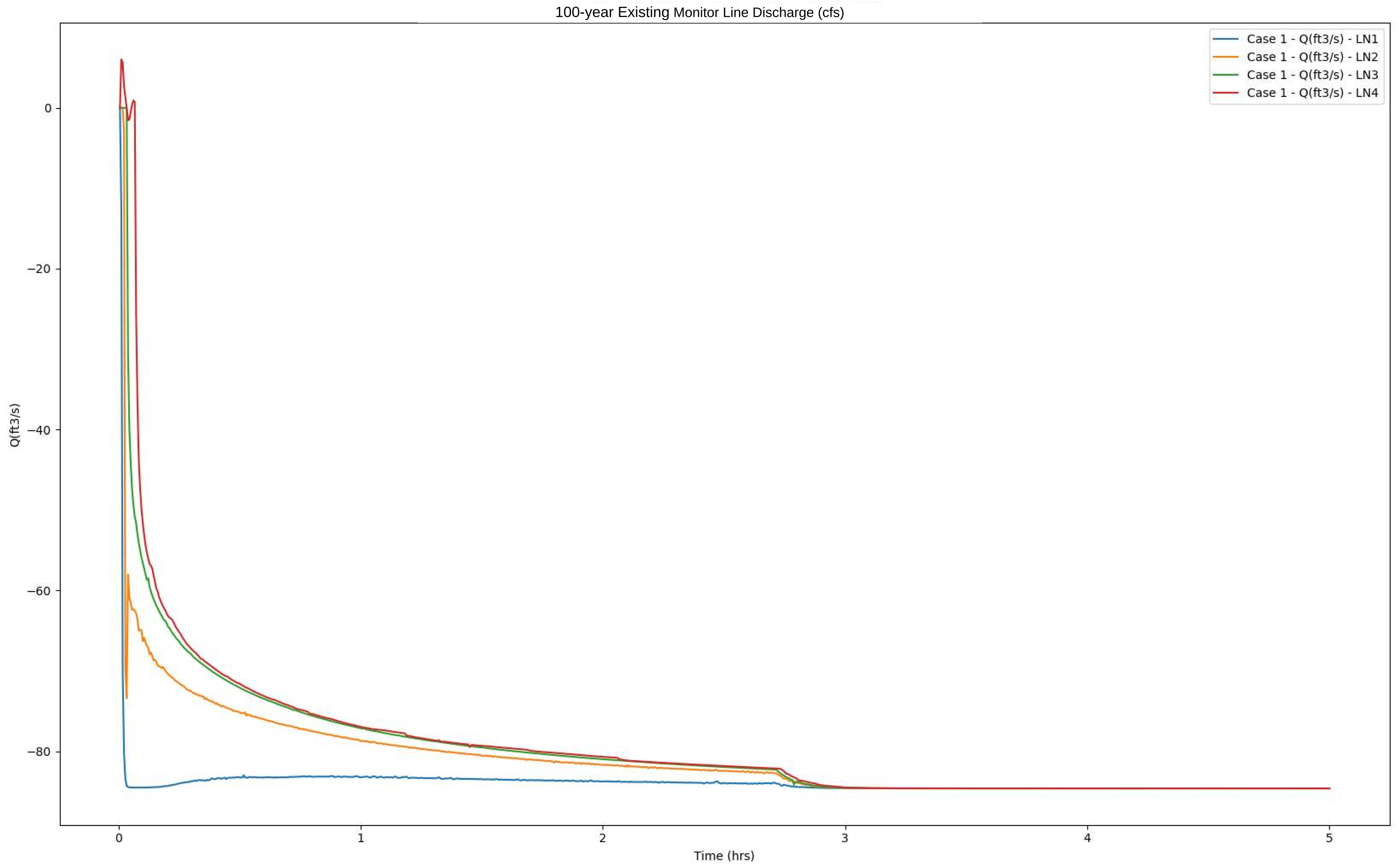
Existing Conditions Monitor Line and Point Locations

Proposed Conditions Monitor Line and Point Locations

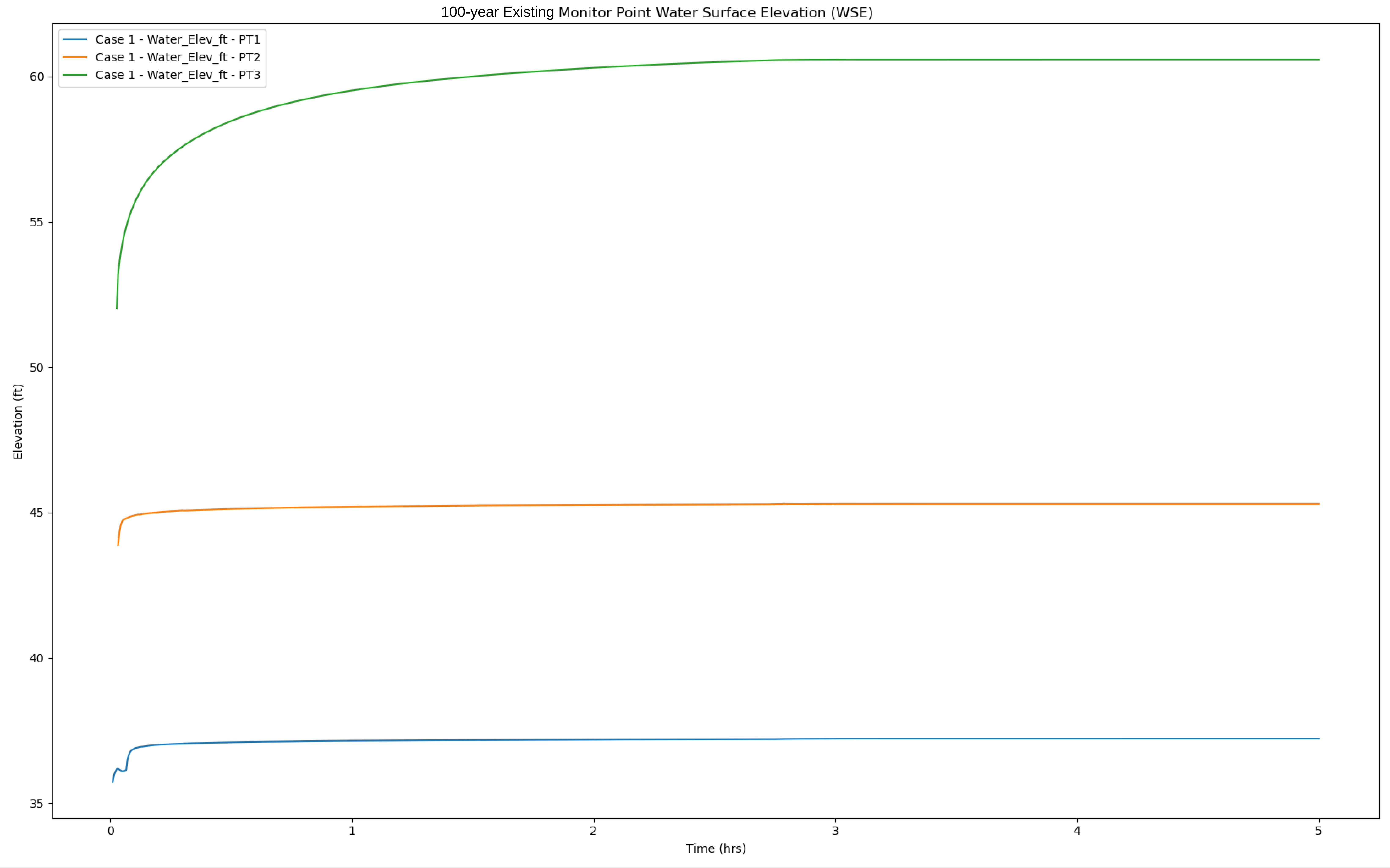
2-year Existing Monitor Line Discharge (cfs)

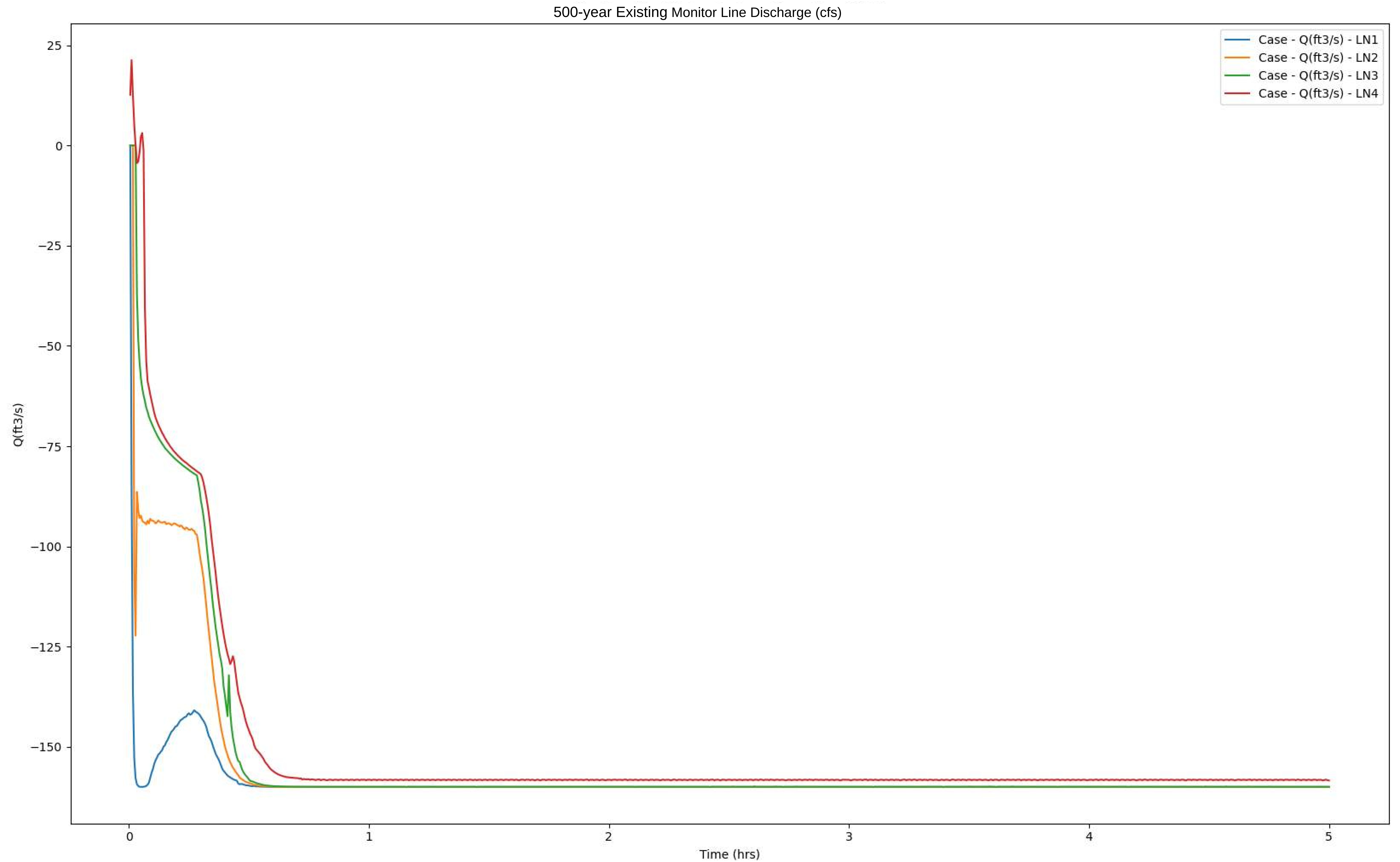


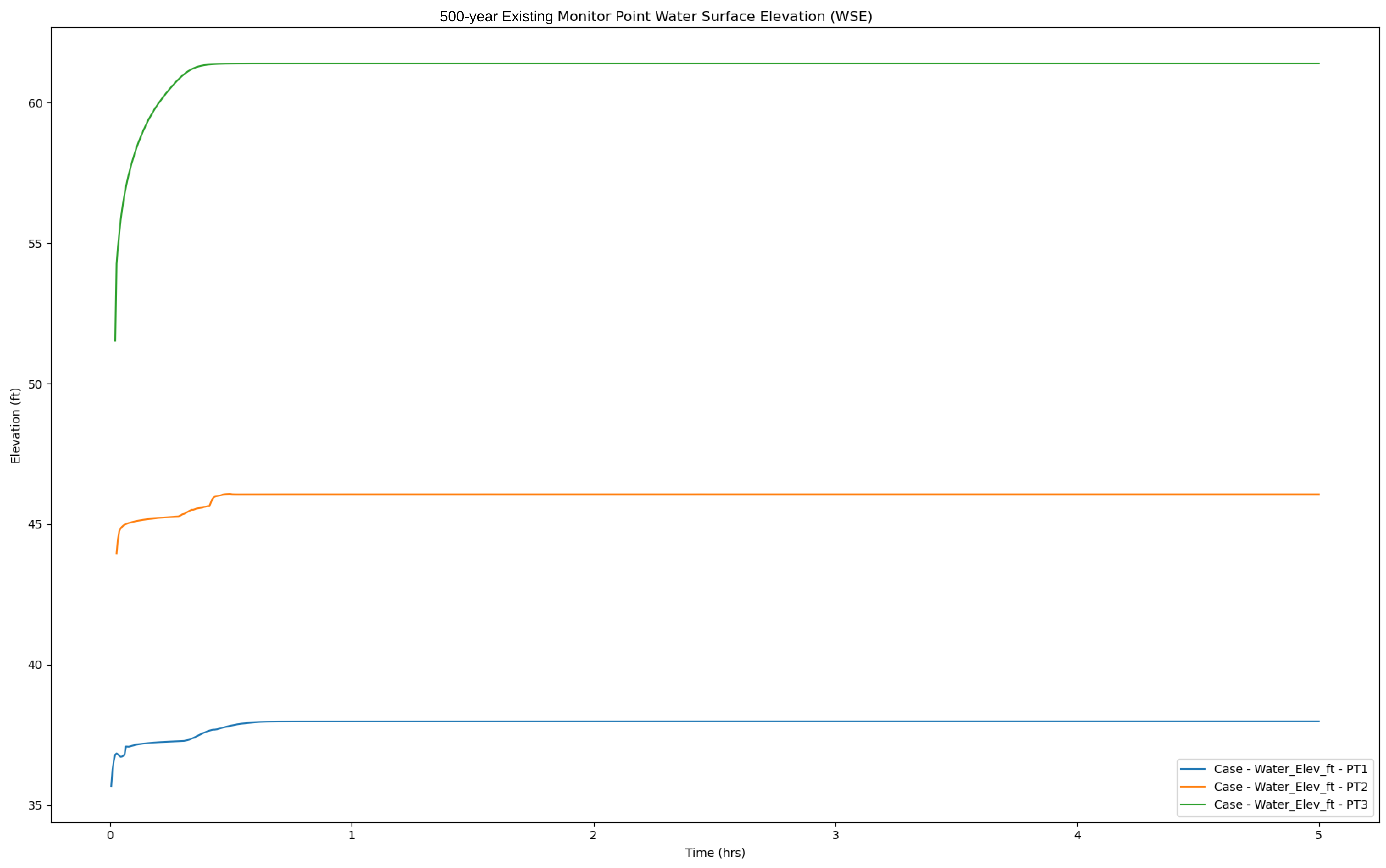

2-year Existing Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
52
50
48
46
44
42
40
38
36
0
1
2
3
4
5
Case 1 - Water_Elev_ft - PT1
Case 1 - Water_Elev_ft - PT2
Case 1 - Water_Elev_ft - PT3

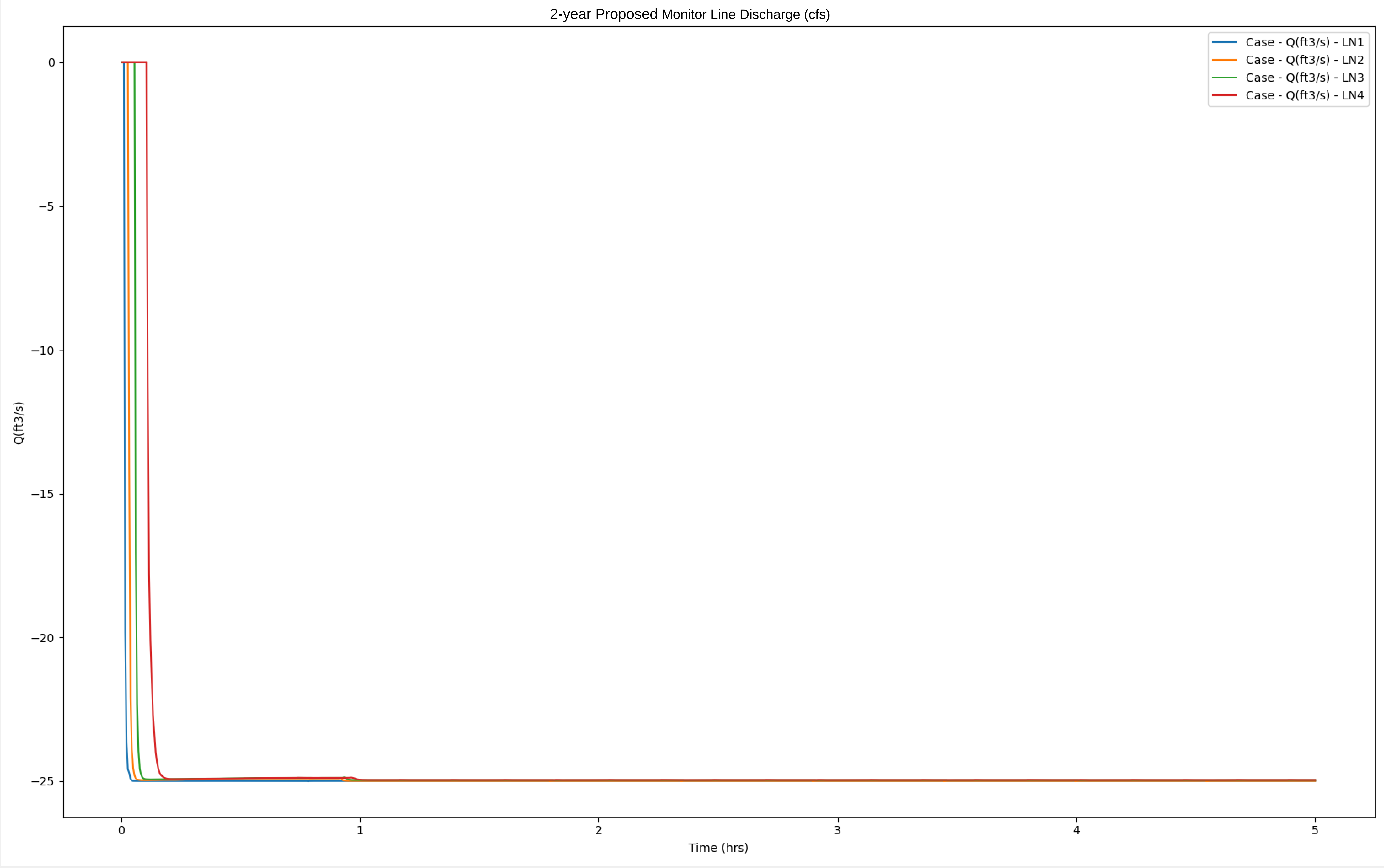


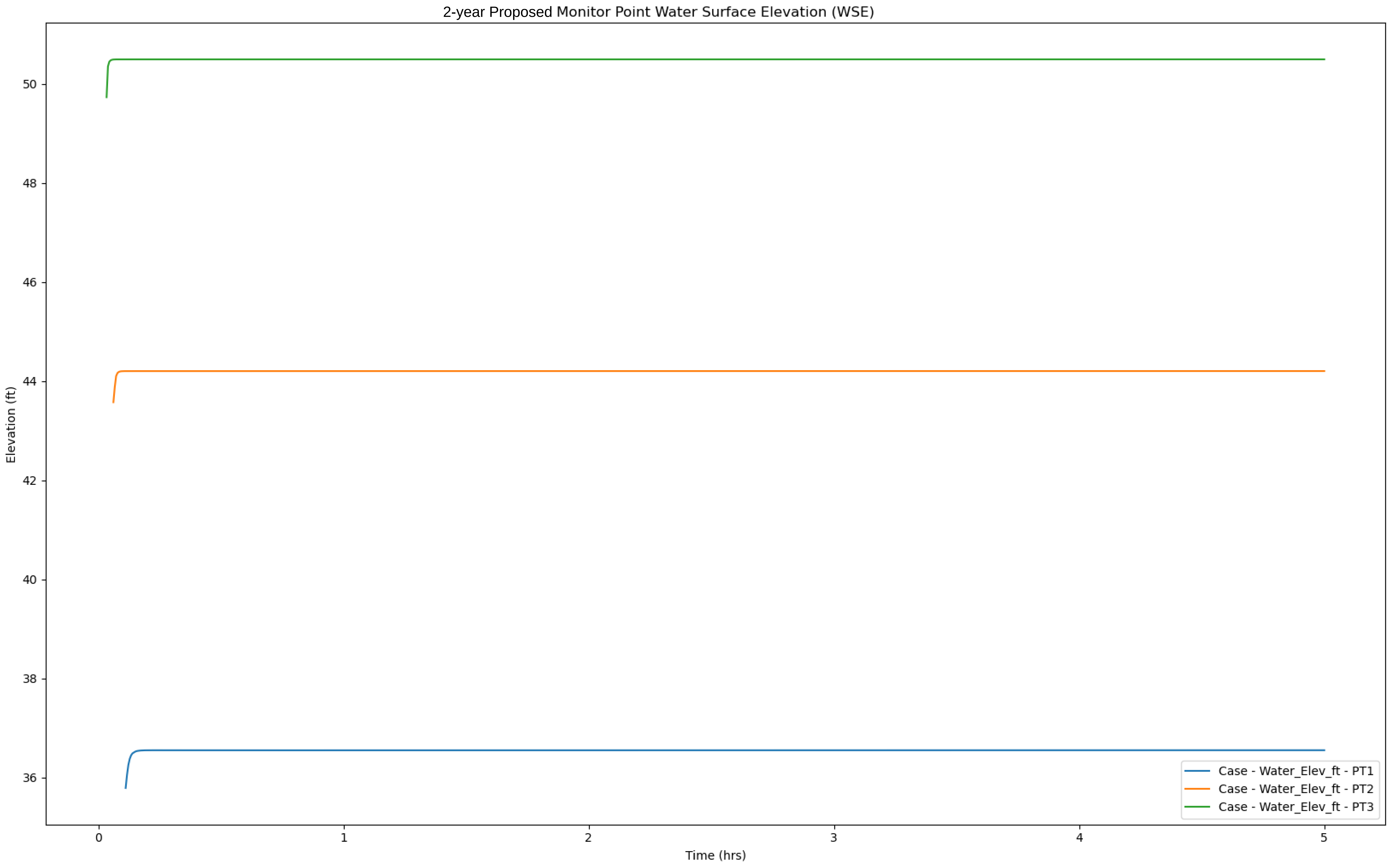
100-year Existing Monitor Line Discharge (cfs)
Case 1 - Q(ft3/s) - LN1
Case 1 - Q(ft3/s) - LN2
Case 1 - Q(ft3/s) - LN3
Case 1 - Q(ft3/s) - LN4
0
−20
−40
−60
−80
Q(ft3/s)
0
1
2
3
4
5
Time (hrs)

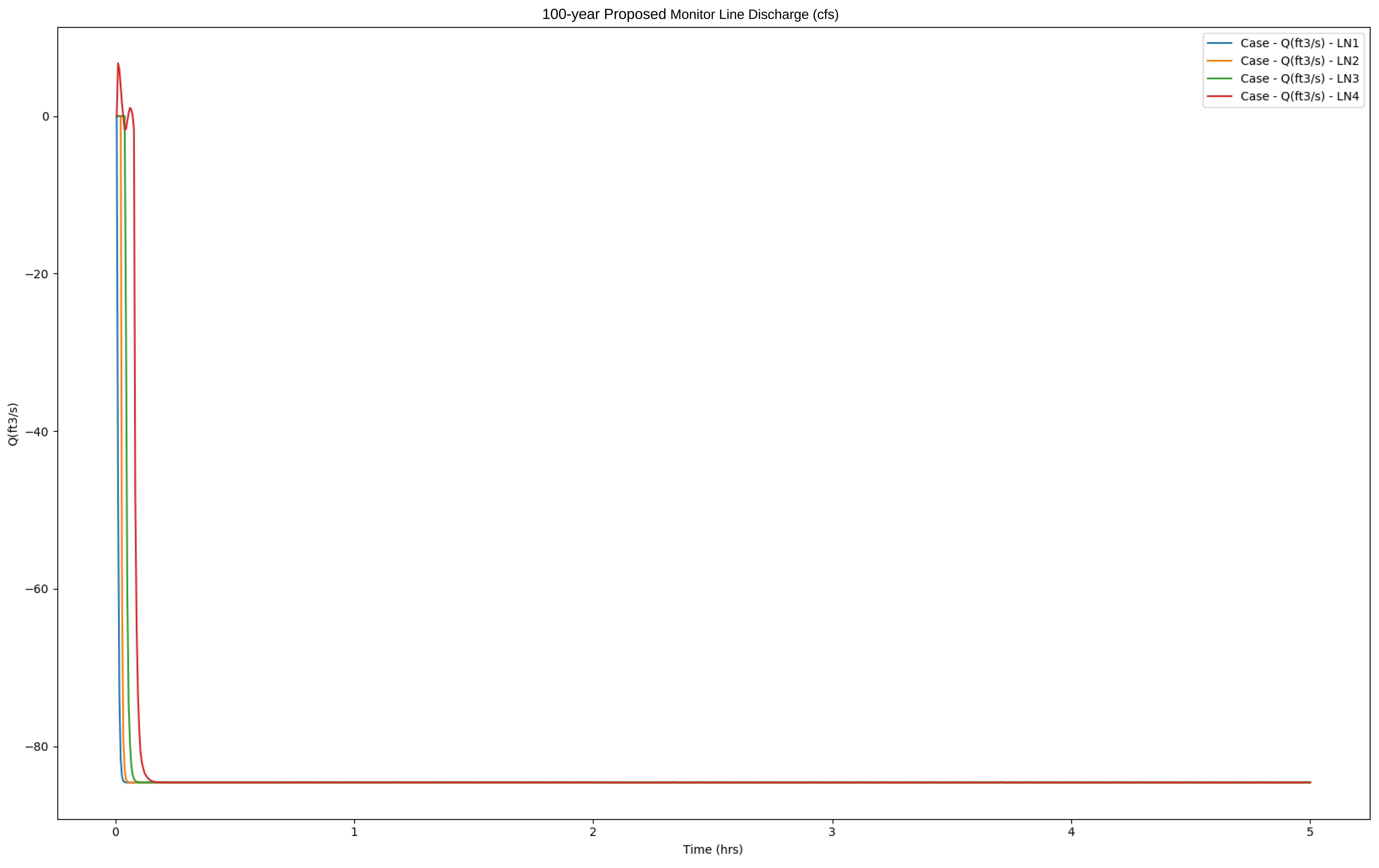

100-year Existing Monitor Point Water Surface Elevation (WSE)
Case 1 - Water_Elev_ft - PT1
Case 1 - Water_Elev_ft - PT2
Case 1 - Water_Elev_ft - PT3
Elevation (ft)
Time (hrs)
35
40
45
50
55
60
0
1
2
3
4
5


500-year Existing Monitor Line Discharge (cfs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
25
0
−25
−50
−75
−100
−125
−150
Q(ft3/s)
0
1
2
3
4
5
Time (hrs)

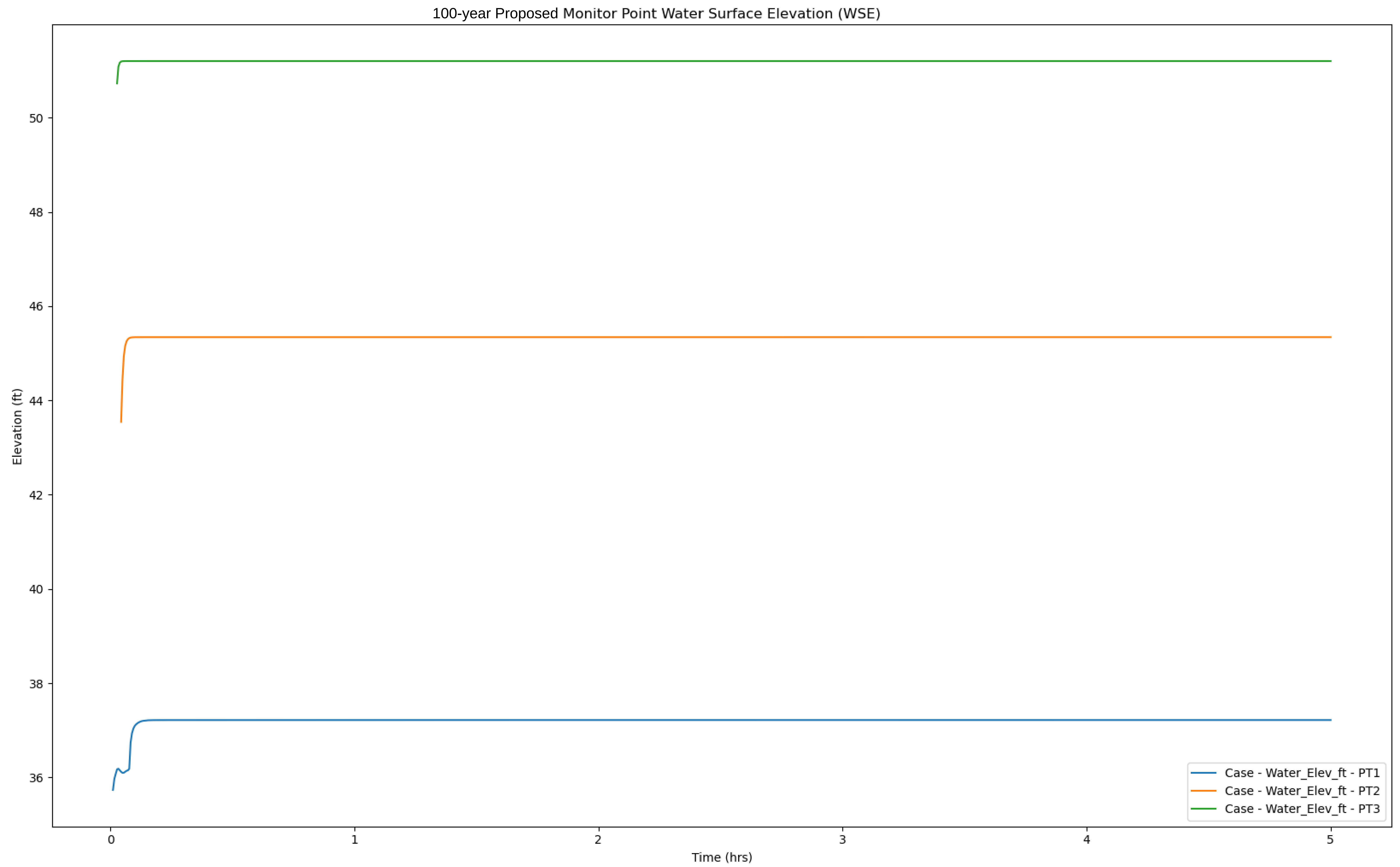

500-year Existing Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
35
40
45
50
55
60
0
1
2
3
4
5
Case - Water_Elev_ft - PT1
Case - Water_Elev_ft - PT2
Case - Water_Elev_ft - PT3

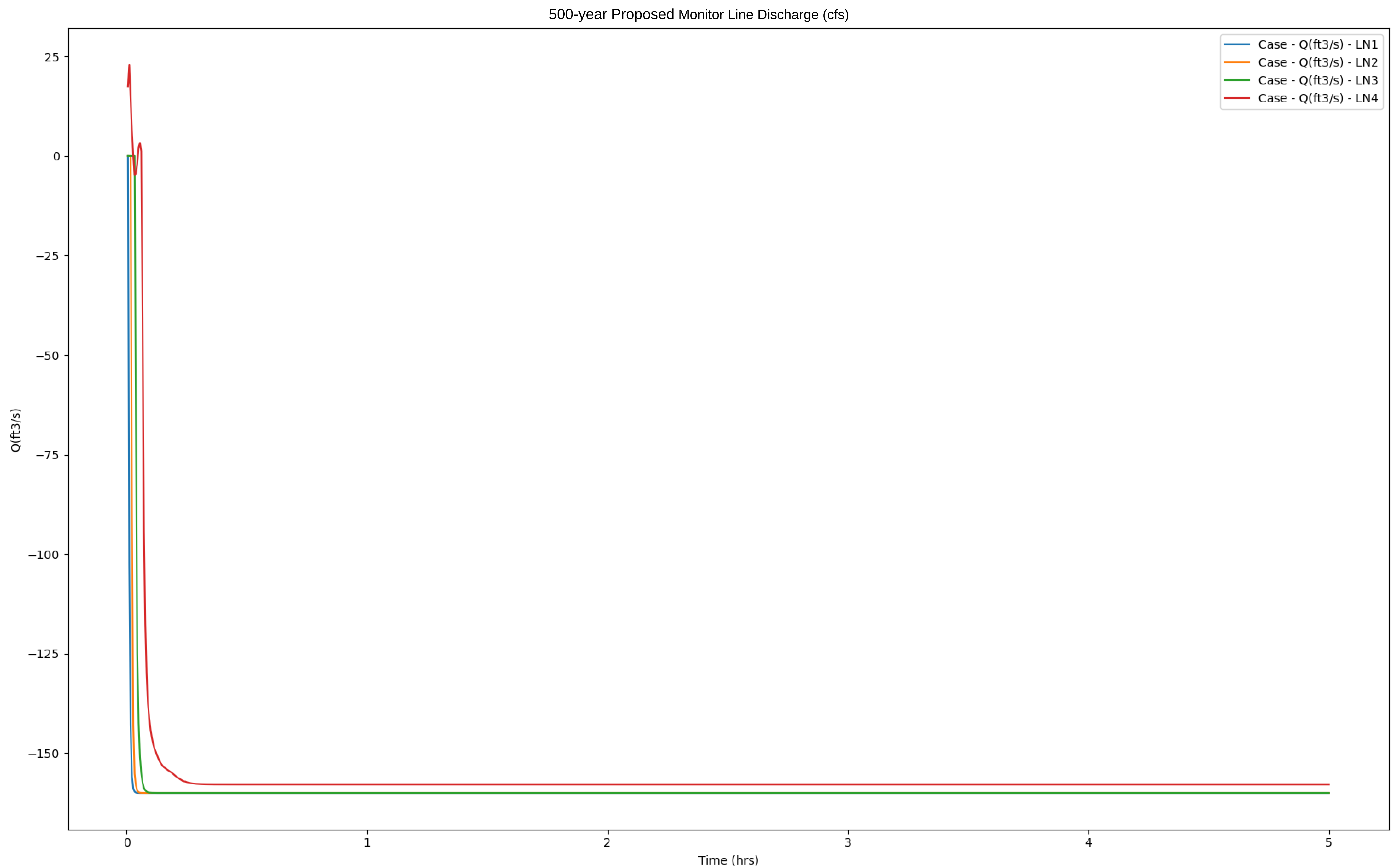

2-year Proposed Monitor Line Discharge (cfs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
0
−5
−10
−15
−20
−25
Q(ft3/s)
0
1
2
3
4
5
Time (hrs)


2-year Proposed Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
50
48
46
44
42
40
38
36
0
1
2
3
4
5
Case - Water_Elev_ft - PT1
Case - Water_Elev_ft - PT2
Case - Water_Elev_ft - PT3

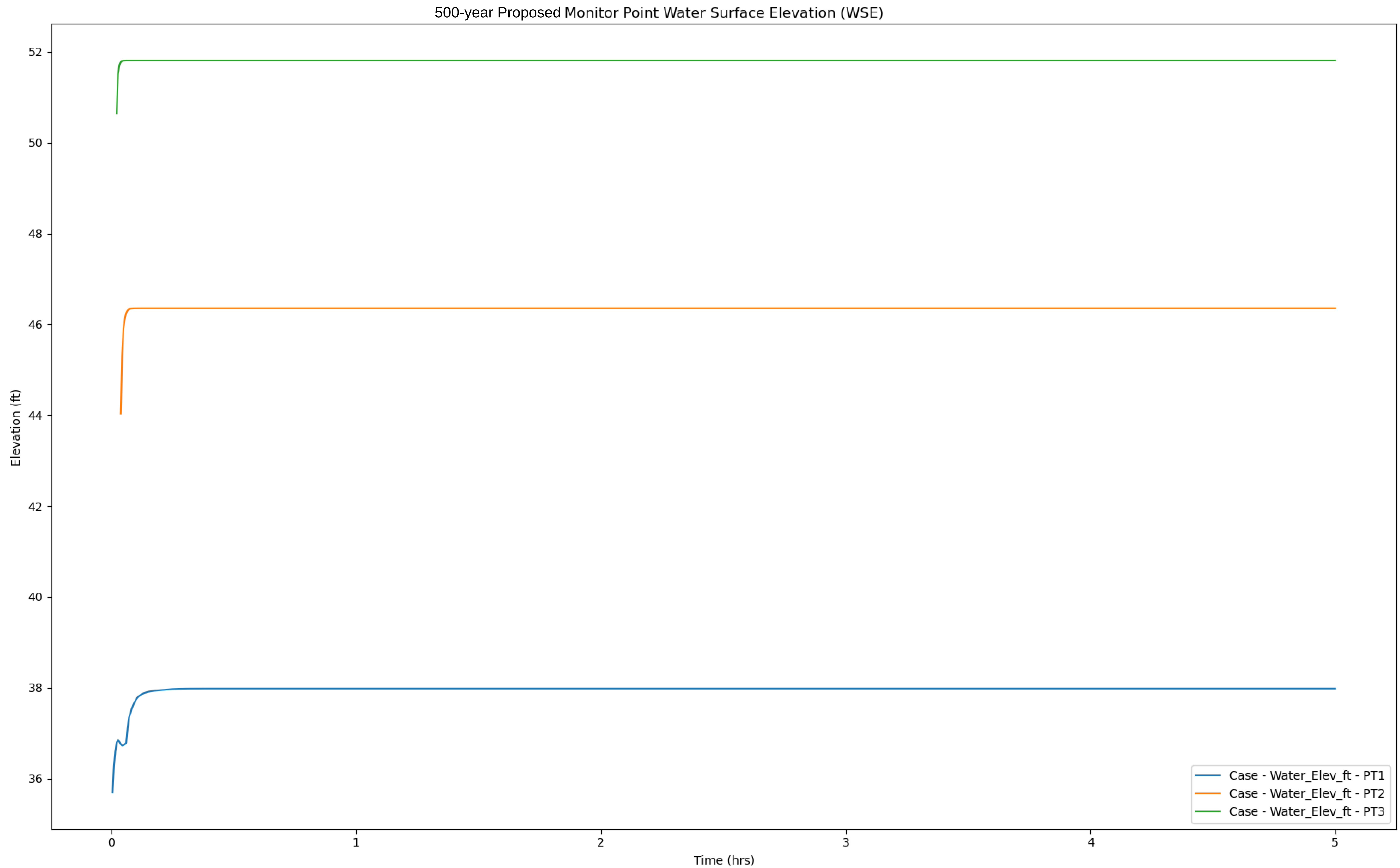


100-year Proposed Monitor Line Discharge (cfs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
0
−20
−40
−60
−80
Q(ft3/s)
0
1
2
3
4
5
Time (hrs)

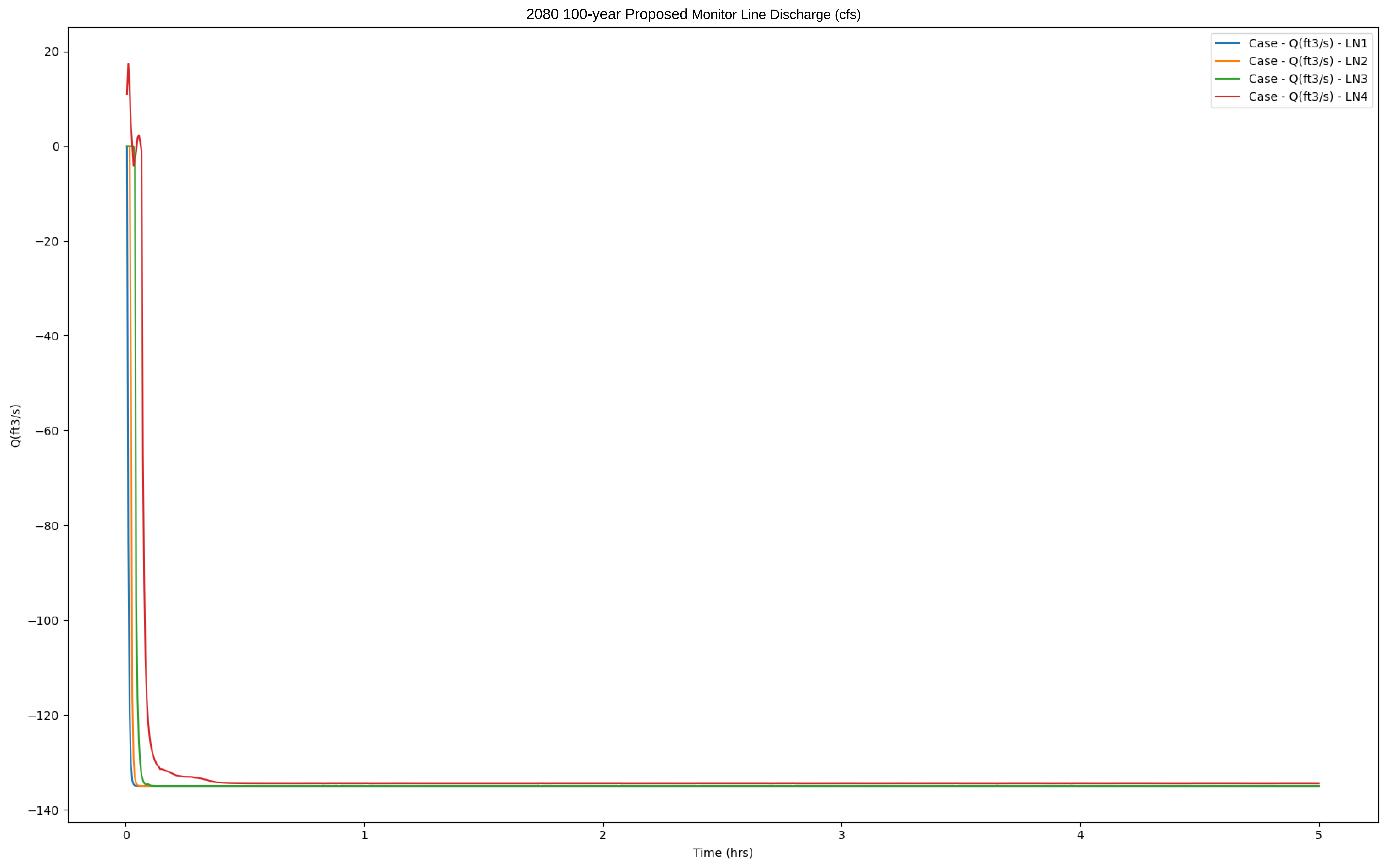

100-year Proposed Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
Case - Water_Elev_ft - PT1
Case - Water_Elev_ft - PT2
Case - Water_Elev_ft - PT3
36
38
40
42
44
46
48
50
0
1
2
3
4
5



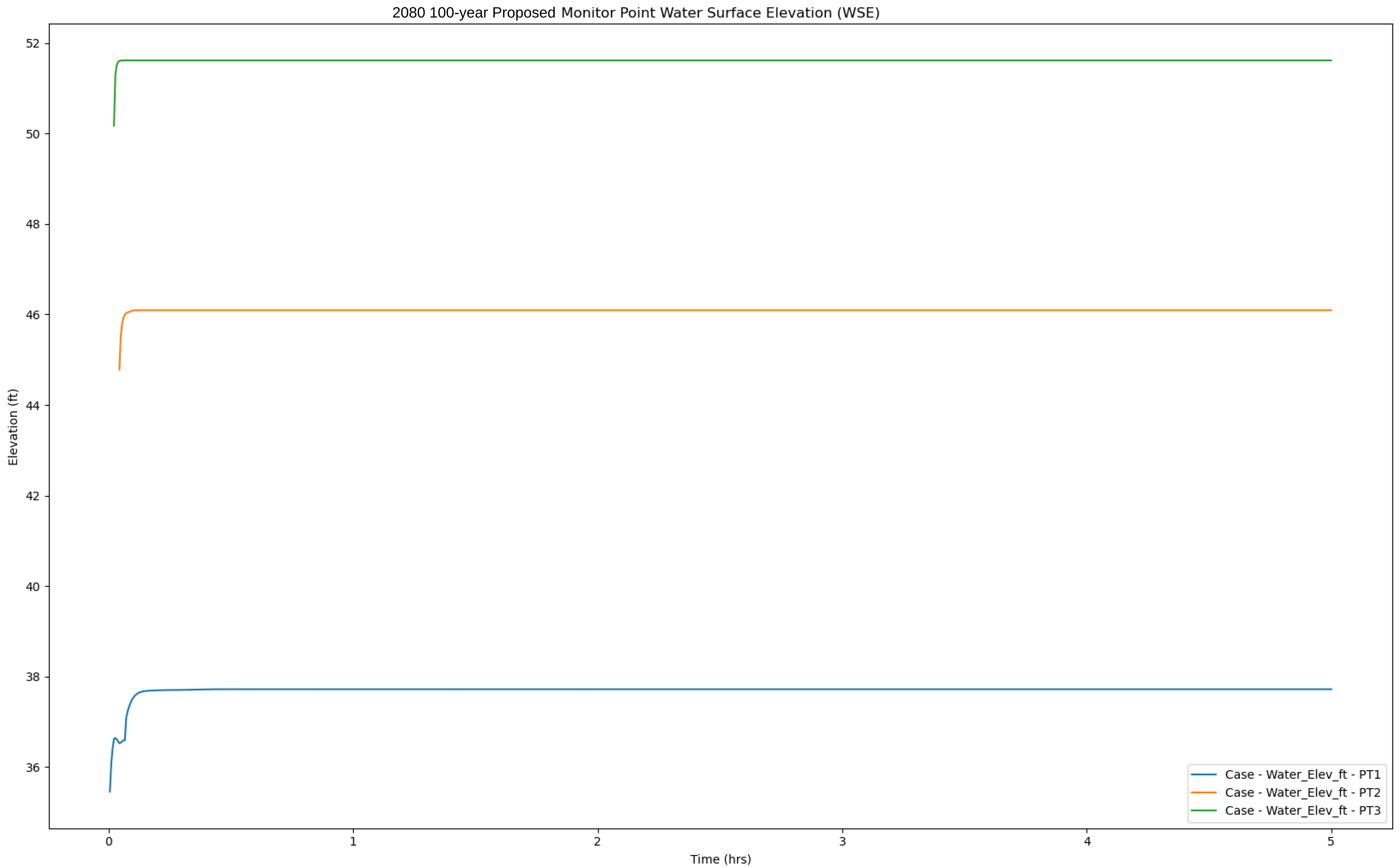
500-year Proposed Monitor Line Discharge (cfs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
Q(ft3/s)
25
0
−25
−50
−75
−100
−125
−150
0
1
2
3
4
5
Time (hrs)



500-year Proposed Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
52
50
48
46
44
42
40
38
36
0
1
2
3
4
5
Case - Water_Elev_ft - PT1
Case - Water_Elev_ft - PT2
Case - Water_Elev_ft - PT3



2080 100-year Proposed Monitor Line Discharge (cfs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
20
0
−20
−40
−60
−80
−100
−120
−140
Q(ft3/s)
0
1
2
3
4
5
Time (hrs)


2080 100-year Proposed Monitor Point Water Surface Elevation (WSE)
Elevation (ft)
Time (hrs)
52
50
48
46
44
42
40
38
36
0
1
2
3
4
5
Case - Water_Elev_ft - PT1
Case - Water_Elev_ft - PT2
Case - Water_Elev_ft - PT3

Appendix J: Reach Assessment (NOT USED)

Appendix K: Preliminary Scour Calculations

SMS Bridge Scour Coverage Figures


Design Flood (2080 100-year) and
Check Flood (500-year)
Scour Arc Locations
(500-year CVI shown)
Scour Arcs
Contracted Section Arc
Approach Arc
Centerline Arc
Bank Arc
Abutment Toe Arc
Width Transporting Sediment
Channel Width
Critical Velocity Index
3
2
1
0
N
Feet (U.S. Survey)
0
25
50

Hydraulic Toolbox Model Output

Contraction Scour

Contraction Scour

2-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.25	ft	
D50	20.421600	mm	0.2 mm is the lower limit for …
Average Velocity Upstream	3.27	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s…	4.71	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	24.99	cfs	
Bottom Width in Contracted Section	7.46	ft	Width should exclude pier wi…
Depth Prior to Scour in Contracted Section	0.70	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.036326	ft/ft	
Discharge in Contracted Section	24.99	cfs	
Discharge Upstream that is Transporting Sediment	16.41	cfs	
Width in Contracted Section	7.46	ft	Remove widths occupied by …
Width Upstream that is Transporting Sediment	4.00	ft	
Depth Prior to Scour in Contracted Section	0.70	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b…	25.527000	mm	
Average Depth in Contracted Section after Scour	0.71	ft	
Scour Depth	0.01	ft	Negative values imply 'zero' …
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.21	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	1.21	ft	
Scour Depth	0.50	ft	Negative values imply 'zero' …
Shear Applied to Bed by Live-Bed Scour	0.1091	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.01	ft	Negative values imply 'zero' …

Contraction Scour

10-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.64	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	3.89	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	4.92	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	48.26	cfs	
Bottom Width in Contracted Section	7.46	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	1.09	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.035838	ft/ft	
Discharge in Contracted Section	48.26	cfs	
Discharge Upstream that is Transporting Sediment	25.47	cfs	
Width in Contracted Section	7.46	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	4.00	ft	
Depth Prior to Scour in Contracted Section	1.09	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	1.25	ft	
Scour Depth	0.16	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.37	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	1.90	ft	
Scour Depth	0.81	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.1909	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.16	ft	Negative values imply 'zero' ...

Contraction Scour

25-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.74	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.08	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	4.98	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	56.71	cfs	
Bottom Width in Contracted Section	7.46	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	1.21	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.035521	ft/ft	
Discharge in Contracted Section	56.71	cfs	
Discharge Upstream that is Transporting Sediment	28.47	cfs	
Width in Contracted Section	7.46	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	4.00	ft	
Depth Prior to Scour in Contracted Section	1.21	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	1.44	ft	
Scour Depth	0.23	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.41	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	2.11	ft	
Scour Depth	0.91	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.2206	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.23	ft	Negative values imply 'zero' ...

Contraction Scour

50-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.81	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.20	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.01	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	61.99	cfs	
Bottom Width in Contracted Section	7.46	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	1.28	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.035339	ft/ft	
Discharge in Contracted Section	61.99	cfs	
Discharge Upstream that is Transporting Sediment	30.32	cfs	
Width in Contracted Section	7.46	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	4.00	ft	
Depth Prior to Scour in Contracted Section	1.28	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	1.55	ft	
Scour Depth	0.27	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.43	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	2.24	ft	
Scour Depth	0.96	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.2395	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.27	ft	Negative values imply 'zero' ...

Contraction Scour

100-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.91	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.41	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.05	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	71.05	cfs	
Bottom Width in Contracted Section	7.46	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	1.40	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.035087	ft/ft	
Discharge in Contracted Section	71.05	cfs	
Discharge Upstream that is Transporting Sediment	33.73	cfs	
Width in Contracted Section	7.46	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	4.00	ft	
Depth Prior to Scour in Contracted Section	1.40	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	1.74	ft	
Scour Depth	0.34	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.47	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	2.43	ft	
Scour Depth	1.03	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.2743	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.34	ft	Negative values imply 'zero' ...

Contraction Scour

500-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	2.18	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	5.77	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.17	ft/s	
Contraction Scour Condition	Live Bed		
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.036042	ft/ft	
Discharge in Contracted Section	109.75	cfs	
Discharge Upstream that is Transporting Sediment	124.14	cfs	
Width in Contracted Section	7.45	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	9.89	ft	
Depth Prior to Scour in Contracted Section	1.85	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	2.53	ft	
Scour Depth	0.68	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.59	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	2.35	ft	
Scour Depth	0.50	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.6937	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.50	ft	Negative values imply 'zero' ...

Contraction Scour

2080 100-year Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	2.03	ft	
D50	20.421600	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	5.33	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.11	ft/s	
Contraction Scour Condition	Live Bed		
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.036060	ft/ft	
Discharge in Contracted Section	97.79	cfs	
Discharge Upstream that is Transporting Sediment	107.24	cfs	
Width in Contracted Section	7.45	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	9.89	ft	
Depth Prior to Scour in Contracted Section	1.72	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	25.527000	mm	
Average Depth in Contracted Section after Scour	2.29	ft	
Scour Depth	0.57	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.54	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	2.25	ft	
Scour Depth	0.54	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.5900	lb/ft^2	
Shear Required for Movement of D50 Particle	0.2681	lb/ft^2	
Recommendations			
Recommended Scour Depth	0.54	ft	Negative values imply 'zero' ...

Abutment Scour

Abutment Scour

2-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	4.10	cfs/ft	
Unit Discharge in Constricted Area (q2)	3.35	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh…
Upstream Flow Depth	1.25	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.05	ft	Depth at Abutment Toe
Results			
q2 / q1	0.82		
Average Velocity Upstream	3.27	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm…	4.71	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.20		
Flow Depth including Contraction Scour	0.77	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	0.93	ft	Including the long-term scour de…
Scour Hole Depth	-0.12	ft	Negative values imply 'zero' sco…
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will …

Abutment Scour

10-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	6.36	cfs/ft	
Unit Discharge in Constricted Area (q2)	6.47	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.64	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.44	ft	Depth at Abutment Toe
Results			
q2 / q1	1.02		
Average Velocity Upstream	3.89	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	4.92	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.29		
Flow Depth including Contraction Scour	1.36	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	1.75	ft	Including the long-term scour de...
Scour Hole Depth	0.31	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	0.33	ft	

Abutment Scour

25-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	7.11	cfs/ft	
Unit Discharge in Constricted Area (q2)	7.61	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.74	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.55	ft	Depth at Abutment Toe
Results			
q2 / q1	1.07		
Average Velocity Upstream	4.08	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	4.98	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.54		
Flow Depth including Contraction Scour	1.56	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	2.40	ft	Including the long-term scour de...
Scour Hole Depth	0.85	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	0.88	ft	

Abutment Scour

50-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	7.57	cfs/ft	
Unit Discharge in Constricted Area (q2)	8.31	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh…
Upstream Flow Depth	1.81	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.62	ft	Depth at Abutment Toe
Results			
q2 / q1	1.10		
Average Velocity Upstream	4.20	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm…	5.01	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.61		
Flow Depth including Contraction Scour	1.68	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	2.71	ft	Including the long-term scour de…
Scour Hole Depth	1.09	ft	Negative values imply 'zero' sco…
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will …
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	1.13	ft	

Abutment Scour

100-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	8.42	cfs/ft	
Unit Discharge in Constricted Area (q2)	9.53	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.91	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.74	ft	Depth at Abutment Toe
Results			
q2 / q1	1.13		
Average Velocity Upstream	4.41	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	5.05	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.67		
Flow Depth including Contraction Scour	1.89	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	3.16	ft	Including the long-term scour de...
Scour Hole Depth	1.42	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	1.47	ft	

Abutment Scour

500-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	12.56	cfs/ft	
Unit Discharge in Constricted Area (q2)	14.72	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	2.18	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	2.19	ft	Depth at Abutment Toe
Results			
q2 / q1	1.17		
Average Velocity Upstream	5.77	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	5.17	ft/s	
Scour Condition	Live Bed		
Scour Condition	a (Main Channel)		
Amplification Factor	1.72		
Flow Depth including Contraction Scour	2.50	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	4.29	ft	Including the long-term scour de...
Scour Hole Depth	2.10	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	2.17	ft	

Abutment Scour

2080 100-year Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	10.85	cfs/ft	
Unit Discharge in Constricted Area (q2)	13.12	cfs/ft	
D50	20.421600	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	2.03	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	2.06	ft	Depth at Abutment Toe
Results			
q2 / q1	1.21		
Average Velocity Upstream	5.33	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	5.11	ft/s	
Scour Condition	Live Bed		
Scour Condition	a (Main Channel)		
Amplification Factor	1.74		
Flow Depth including Contraction Scour	2.39	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	4.17	ft	Including the long-term scour de...
Scour Hole Depth	2.11	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	2.18	ft	

Appendix L: Floodplain Analysis (FHD ONLY)

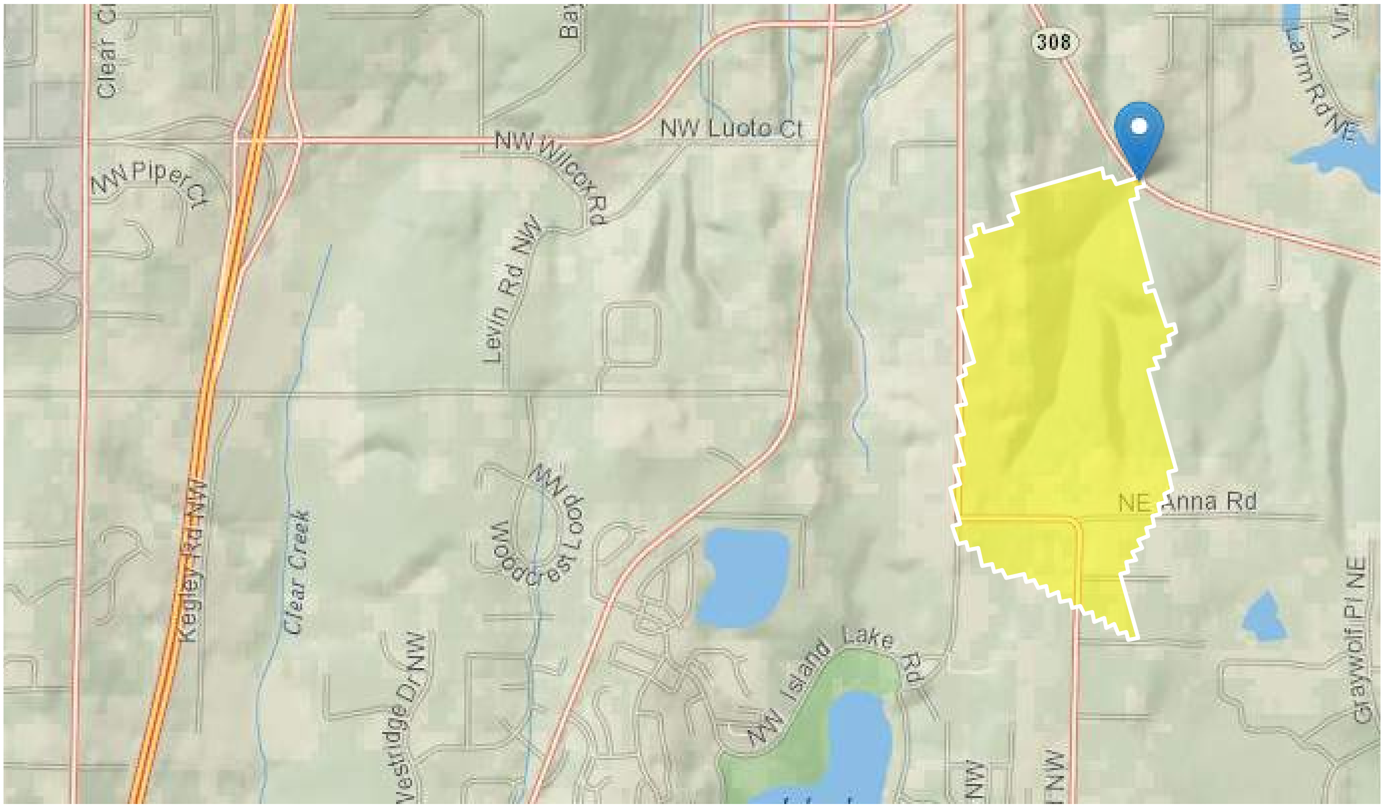
Appendix M: Scour Countermeasure Calculations (FHD ONLY)

Appendix N: Hydrology Calculations

991000 Streamstats

991000 StreamStats Report

Region ID: WA
Workspace ID: WA20211122173614183000
Clicked Point (Latitude, Longitude): 47.70001, -122.64682
Time: 2021-11-22 09:36:40 -0800



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	0.3	square miles
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM	40.4	inches
PRECIP	Mean Annual Precipitation	40.6	inches
BSLDEM30M	Mean basin slope computed from 30 m DEM	10.7	percent
CANOPY_PCT	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267	56.1	percent

Parameter Code	Parameter Description	Value	Unit
ELEV	Mean Basin Elevation	273	feet
ELEVMAX	Maximum basin elevation	378	feet
MINBELEV	Minimum basin elevation	55.9	feet
NFSL30	North-Facing Slopes Greater Than 30 Percent	0.23	percent
RELIEF	Maximum - minimum elevation	322	feet
SLOP30_30M	Percent area with slopes greater than 30 percent from 30-meter DEM.	1.61	percent

Peak-Flow Statistics Parameters [Peak Region 3 2016 5118]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	0.08	2610
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	40.4	inches	33.2	168

Peak-Flow Statistics Flow Report [Peak Region 3 2016 5118]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	6.45	ft^3/s	3.2	13	43.2
20-percent AEP flood	10.3	ft^3/s	5	21.2	44.4
10-percent AEP flood	13	ft^3/s	6.22	27.2	45.6
4-percent AEP flood	16.5	ft^3/s	7.57	36	48.1
2-percent AEP flood	19.1	ft^3/s	8.49	43	50.5
1-percent AEP flood	21.9	ft^3/s	9.53	50.3	51.8
0.5-percent AEP flood	24.6	ft^3/s	10.3	58.7	54.2
0.2-percent AEP flood	28.5	ft^3/s	11.4	71.2	57.7

Peak-Flow Statistics Citations

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E.,2016, Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.1, October 2016): U.S. Geological Survey Scientific Investigations Report 2016–5118, 70 p. (http://dx.doi.org/10.3133/sir20165118)

Low-Flow Statistics Parameters [Low Flow Western 2 var 2012 5078]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	0.1	48.9
PRECIP	Mean Annual Precipitation	40.6	inches	25.1	143

Low-Flow Statistics Flow Report [Low Flow Western 2 var 2012 5078]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE
7 Day 10 Year Low Flow	0.0197	ft^3/s	114

Low-Flow Statistics Citations

Curran, C.A., Eng, Ken, and Konrad, C.P.,2012, Analysis of low flows and selected methods for estimating low-flow characteristics at partial-record and ungaged stream sites in western Washington: U.S. Geological Survey Scientific Investigations Report 2012-5078, 46 p. (http://pubs.usgs.gov/sir/2012/5078/)

Bankfull Statistics Parameters [Pacific Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	6.1776	8079.9147

Bankfull Statistics Parameters [Pacific Border P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	6.169878	3938.976756

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	0.07722	59927.7393

Bankfull Statistics Parameters [Pac Maritime Mtn CastroJackson 2001]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.3	square miles	54.8	3093

Bankfull Statistics Disclaimers [Pacific Mountain System D Bieger 2015]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors

Bankfull Statistics Flow Report [Pacific Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	8.19	ft
Bieger_D_channel_depth	0.701	ft
Bieger_D_channel_cross_sectional_area	7.94	ft^2

Bankfull Statistics Disclaimers [Pacific Border P Bieger 2015]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors

Bankfull Statistics Flow Report [Pacific Border P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	6.46	ft
Bieger_P_channel_cross_sectional_area	6.39	ft^2
Bieger_P_channel_depth	0.634	ft

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	8.11	ft
Bieger_USA_channel_depth	0.933	ft
Bieger_USA_channel_cross_sectional_area	8.92	ft^2

Bankfull Statistics Disclaimers [Pac Maritime Mtn CastroJackson 2001]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors

Bankfull Statistics Flow Report [Pac Maritime Mtn CastroJackson 2001]

Statistic	Value	Unit
Bankfull Width	7.38	ft
Bankfull Depth	0.413	ft
Bankfull Area	5.86	ft^2
Bankfull Streamflow	40.6	ft^3/s

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	8.19	ft
Bieger_D_channel_depth	0.701	ft
Bieger_D_channel_cross_sectional_area	7.94	ft^2
Bieger_P_channel_width	6.46	ft
Bieger_P_channel_cross_sectional_area	6.39	ft^2
Bieger_P_channel_depth	0.634	ft
Bieger_USA_channel_width	8.11	ft
Bieger_USA_channel_depth	0.933	ft
Bieger_USA_channel_cross_sectional_area	8.92	ft^2
Bankfull Width	7.38	ft
Bankfull Depth	0.413	ft
Bankfull Area	5.86	ft^2
Bankfull Streamflow	40.6	ft^3/s

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_can

Castro, J.M, and Jackson, P.L.Castro, J.M, and Jackson, P.L., 2001, Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometery Relationships: Patterns in the Pacific Northwest, USA, Journal of the American Water Resources Association, Volume 37, No. 5, 14 p. (https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2001.tb03636.x)

Application Version: 4.6.2
StreamStats Services Version: 1.2.22
NSS Services Version: 2.1.2

991000 MGS Flood

MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.57
Program License Number: 200410013
Project Simulation Performed on: 05/02/2022 1:35 PM
Report Generation Date: 05/02/2022 1:39 PM

Input File Name: 991000 Unnamed Trib.fld
Project Name: UNT to Liberty Bay, SR 308 MP 2.16, WDFW ID 991000
Analysis Title:
Comments:

PRECIPITATION INPUT

Computational Time Step (Minutes): 5

Extended Precipitation Time Series Selected
Climatic Region Number: 5

Full Period of Record Available used for Routing
Precipitation Station : 95004805 Puget West 48 in_5min 10/01/1939-10/01/2097
Evaporation Station : 951048 Puget West 48 in MAP
Evaporation Scale Factor : 0.750

HSPF Parameter Region Number: 3
HSPF Parameter Region Name : USGS Default

********** Default HSPF Parameters Used (Not Modified by User) ***************

************************ WATERSHED DEFINITION *************************

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	198.400	198.400
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	198.400	198.400

---------------------SCENARIO: PREDEVELOPED

Number of Subbasins: 1

---------- Subbasin : Subbasin 1 ----------

	-------Area (Acres) --------
Till Forest	108.800
Till Grass	79.600
Impervious	10.000
Subbasin Total	198.400

---------------------SCENARIO: POSTDEVELOPED

Number of Subbasins: 1

---------- Subbasin : Subbasin 1 ----------

	-------Area (Acres) --------
Till Forest	108.800
Till Grass	79.600
Impervious	10.000
Subbasin Total	198.400

**********************FLOOD FREQUENCY AND DURATION STATISTICS*******************

----------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 1
Number of Links: 0

----------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 1
Number of Links: 0

***********Compliance Point Results *************

Scenario Predeveloped Compliance Subbasin: Subbasin 1

Scenario Postdeveloped Compliance Subbasin: Subbasin 1

***** Point of Compliance Flow Frequency Data *****
Recurrence Interval Computed Using Gringorten Plotting Position

Predevelopment Runoff		Postdevelopment Runoff	
Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	25.082	2-Year	25.082
5-Year	41.017	5-Year	41.017
10-Year	51.077	10-Year	51.077
25-Year	62.594	25-Year	62.594
50-Year	70.164	50-Year	70.164
100-Year	84.605	100-Year	84.605
200-Year	117.061	200-Year	117.061
500-Year	160.311	500-Year	160.311

Clear Creek Streamstats

StreamStats Report

Region ID: WA
Workspace ID: WA20221221072214620000
Clicked Point (Latitude, Longitude): 47.66945, -122.69132
Time: 2022-12-21 00:22:38 -0700

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
BSLDEM30M	Mean basin slope computed from 30 m DEM	6	percent
CANOPY_PCT	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267	54	percent
DRNAREA	Area that drains to a point on a stream	3.25	square miles
ELEV	Mean Basin Elevation	301	feet
ELEVMAX	Maximum basin elevation	486	feet
MINBELEV	Minimum basin elevation	80.3	feet
NFSL30	North-Facing Slopes Greater Than 30 Percent	0	percent
PRECIP	Mean Annual Precipitation	44.5	inches
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM	43.8	inches
RELIEF	Maximum - minimum elevation	406	feet
SLOP30_30M	Percent area with slopes greater than 30 percent from 30-meter DEM.	0	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Region 3 2016 5118]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	0.08	2610
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	43.8	inches	33.2	168

Peak-Flow Statistics Flow Report [Peak Region 3 2016 5118]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	63.3	ft^3/s	31.8	126	43.2

Statistic	Value	Unit	PIl	PIu	ASEp
20-percent AEP flood	100	ft^3/s	49.1	204	44.4
10-percent AEP flood	126	ft^3/s	61.1	260	45.6
4-percent AEP flood	159	ft^3/s	74	342	48.1
2-percent AEP flood	184	ft^3/s	83	408	50.5
1-percent AEP flood	211	ft^3/s	93.3	477	51.8
0.5-percent AEP flood	238	ft^3/s	101	559	54.2
0.2-percent AEP flood	276	ft^3/s	112	677	57.7

Peak-Flow Statistics Citations

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E.,2016, Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.1, October 2016): U.S. Geological Survey Scientific Investigations Report 2016–5118, 70 p. (http://dx.doi.org/10.3133/sir20165118)

Low-Flow Statistics

Low-Flow Statistics Parameters [Low Flow Western 2 var 2012 5078]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	0.1	48.9
PRECIP	Mean Annual Precipitation	44.5	inches	25.1	143

Low-Flow Statistics Flow Report [Low Flow Western 2 var 2012 5078]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE
7 Day 10 Year Low Flow	0.359	ft^3/s	114

Low-Flow Statistics Citations

Curran, C.A., Eng, Ken, and Konrad, C.P.,2012, Analysis of low flows and selected methods for estimating low-flow characteristics at partial-record and ungaged stream sites in western Washington: U.S. Geological Survey Scientific Investigations Report 2012-5078, 46 p. (http://pubs.usgs.gov/sir/2012/5078/)

Bankfull Statistics

Bankfull Statistics Parameters [Pacific Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	6.1776	8079.9147

Bankfull Statistics Parameters [Pacific Border P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	6.169878	3938.976756

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	0.07722	59927.7393

Bankfull Statistics Parameters [Pac Maritime Mtn CastroJackson 2001]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	3.25	square miles	54.8	3093

Bankfull Statistics Disclaimers [Pacific Mountain System D Bieger 2015]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Bankfull Statistics Flow Report [Pacific Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	21.2	ft
Bieger_D_channel_depth	1.41	ft
Bieger_D_channel_cross_sectional_area	37.5	ft^2

Bankfull Statistics Disclaimers [Pacific Border P Bieger 2015]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Bankfull Statistics Flow Report [Pacific Border P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	18.4	ft
Bieger_P_channel_cross_sectional_area	34.7	ft^2
Bieger_P_channel_depth	1.39	ft

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	18.8	ft
Bieger_USA_channel_depth	1.55	ft
Bieger_USA_channel_cross_sectional_area	32.3	ft^2

Bankfull Statistics Disclaimers [Pac Maritime Mtn CastroJackson 2001]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Bankfull Statistics Flow Report [Pac Maritime Mtn CastroJackson 2001]

Statistic	Value	Unit
Bankfull Width	20.6	ft
Bankfull Depth	1.05	ft
Bankfull Area	34.1	ft^2
Bankfull Streamflow	201	ft^3/s

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	21.2	ft
Bieger_D_channel_depth	1.41	ft
Bieger_D_channel_cross_sectional_area	37.5	ft^2
Bieger_P_channel_width	18.4	ft
Bieger_P_channel_cross_sectional_area	34.7	ft^2
Bieger_P_channel_depth	1.39	ft
Bieger_USA_channel_width	18.8	ft
Bieger_USA_channel_depth	1.55	ft
Bieger_USA_channel_cross_sectional_area	32.3	ft^2
Bankfull Width	20.6	ft
Bankfull Depth	1.05	ft
Bankfull Area	34.1	ft^2

Statistic	Value	Unit
Bankfull Streamflow	201	ft^3/s

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)
Castro, J.M, and Jackson, P.L.Castro, J.M, and Jackson, P.L., 2001, Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometery Relationships: Patterns in the Pacific Northwest, USA, Journal of the American Water Resources Association, Volume 37, No. 5, 14 p. (https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2001.tb03636.x)

Application Version: 4.11.1
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.1

Clear Creek Gage Data Analysis

```
-------------------------------
Bulletin 17C (Java) Frequency Analysis
    09 Jan 2023   08:56 PM
-------------------------------


--- Input Data ---

Analysis Name: ClearCreek_Bulletin17C
Description:

Data Set Name: CLEARCREEK-MAX-FLOW
DSS File Name:
D:\WashDOT_PHD\GECphdBundle1\Hydrology\ClearCreek_Kitsap_Gage_Data\FreqAnalysis\Clear
CreekFreqAnalysis.dss
DSS Pathname: /CLEARCREEK/MAX/FLOW/01jan1900/IR-YEAR/CFS - WY/

Report File Name:
D:\WashDOT_PHD\GECphdBundle1\Hydrology\ClearCreek_Kitsap_Gage_Data\FreqAnalysis\Bulle
tin17Results\ClearCreek_Bulletin17C\ClearCreek_Bulletin17C.rpt
XML File Name:
D:\WashDOT_PHD\GECphdBundle1\Hydrology\ClearCreek_Kitsap_Gage_Data\FreqAnalysis\Bulle
tin17Results\ClearCreek_Bulletin17C\ClearCreek_Bulletin17C.xml

Start Date:
End Date:

Skew Option: Use Regional Skew
Regional Skew: -0.07
Regional Skew MSE: 0.18

Plotting Position Type: Hirsch-Stedinger

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Display ordinate values using 1 digits in fraction part of value

--- End of Input Data ---
```

<< EMA Representation of Data >>
CLEARCREEK-MAX-FLOW

Year	Peak	Value Low	Value High	Threshold Low	Threshold High	Type
2001	22.0	22.0	22.0	1.0E-99	1.0E99	Syst
2002	215.0	215.0	215.0	1.0E-99	1.0E99	Syst
2003	69.0	69.0	69.0	1.0E-99	1.0E99	Syst
2012	80.1	80.1	80.1	1.0E-99	1.0E99	Syst
2013	265.4	265.4	265.4	1.0E-99	1.0E99	Syst
2014	36.7	36.7	36.7	1.0E-99	1.0E99	Syst
2015	38.9	38.9	38.9	1.0E-99	1.0E99	Syst
2016	135.4	135.4	135.4	1.0E-99	1.0E99	Syst
2017	165.0	165.0	165.0	1.0E-99	1.0E99	Syst
2018	87.0	87.0	87.0	1.0E-99	1.0E99	Syst
2019	44.8	44.8	44.8	1.0E-99	1.0E99	Syst
2020	54.6	54.6	54.6	1.0E-99	1.0E99	Syst
2021	152.4	152.4	152.4	1.0E-99	1.0E99	Syst
2022	154.5	154.5	154.5	1.0E-99	1.0E99	Syst
2023	32.0	32.0	32.0	1.0E-99	1.0E99	Syst

```
--------------------------------------------------------------------------------------
------------
  Fitted log10 Moments                                  Mean      Variance    Std Dev
Skew
--------------------------------------------------------------------------------------
------------
  EMA at-site data w/o regional info                  1.903345    0.110584    0.332542
-0.048793
  EMA w/ regional info and B17b MSE(G)                1.903345    0.110584    0.332542
-0.070000
  EMA w/ regional info and specified MSE(G)           1.903345    0.110584    0.332542
-0.070000
--------------------------------------------------------------------------------------
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  EMA Estimate of MSE[G at-site]                      0.324050
  MSE[G at-site systematic]                           0.324050
  Equivalent Record Length [G at-site]               15.000000
  Equivalent Record Length [Syst+Hist-LowOutl]       15.000000
  Grubbs-Beck Critical Value                          0.000000
```

--- Final Results ---

<< Plotting Positions >>
CLEARCREEK-MAX-FLOW

Events Analyzed		Ordered Events			
Day Mon Year	FLOW CFS	Rank	Water Year	FLOW CFS	H-S Plot Pos
22 Aug 2001	22.0	1	2013	265.4	6.25
16 Dec 2001	215.0	2	2002	215.0	12.50
13 Mar 2003	69.0	3	2017	165.0	18.75
01 Jan 2004	---	4	2022	154.5	25.00
01 Jan 2005	---	5	2021	152.4	31.25
01 Jan 2006	---	6	2016	135.4	37.50
01 Jan 2007	---	7	2018	87.0	43.75
01 Jan 2008	---	8	2012	80.1	50.00
01 Jan 2009	---	9	2003	69.0	56.25
01 Jan 2010	---	10	2020	54.6	62.50
01 Jan 2011	---	11	2019	44.8	68.75
15 Mar 2012	80.1	12	2015	38.9	75.00
19 Nov 2012	265.4	13	2014	36.7	81.25
06 Mar 2014	36.7	14	2023	32.0	87.50
06 Feb 2015	38.9	15	2001	22.0	93.75
09 Mar 2016	135.4	16	2011	---	---
15 Feb 2017	165.0	17	2010	---	---
23 Jan 2018	87.0	18	2009	---	---
04 Jan 2019	44.8	19	2008	---	---
20 Dec 2019	54.6	20	2007	---	---
12 Jan 2021	152.4	21	2006	---	---
06 Jan 2022	154.5	22	2005	---	---
09 Dec 2022	32.0	23	2004	---	---

* Low outlier plotting positions are computed using Median parameters.

<< Frequency Curve >>
CLEARCREEK-MAX-FLOW

Computed Curve FLOW, CFS	Variance Log(EMA)	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
679.6	0.06113	0.200	3,031.1	339.2
547.1	0.04472	0.500	1,943.4	300.2
456.9	0.03436	1.000	1,374.8	268.4
374.8	0.02576	2.000	960.9	234.3
277.7	0.01704	5.000	580.3	185.9
212.3	0.01239	10.000	381.9	147.1
152.9	0.00936	20.000	241.1	107.5
80.8	0.00792	50.000	114.8	56.3
42.1	0.01016	80.000	60.3	26.1
29.8	0.01371	90.000	43.8	16.0
22.4	0.01893	95.000	34.1	10.2
13.0	0.03803	99.000	22.6	4.0

<< Multiple Grubbs-Beck Test P-Values >>

CLEARCREEK-MAX-FLOW

Number Of Low Outliers	P-Values
1	5.579E-1
2	6.458E-1
3	5.179E-1
4	2.598E-1
5	1.551E-1
6	1.344E-1
7	1.859E-1

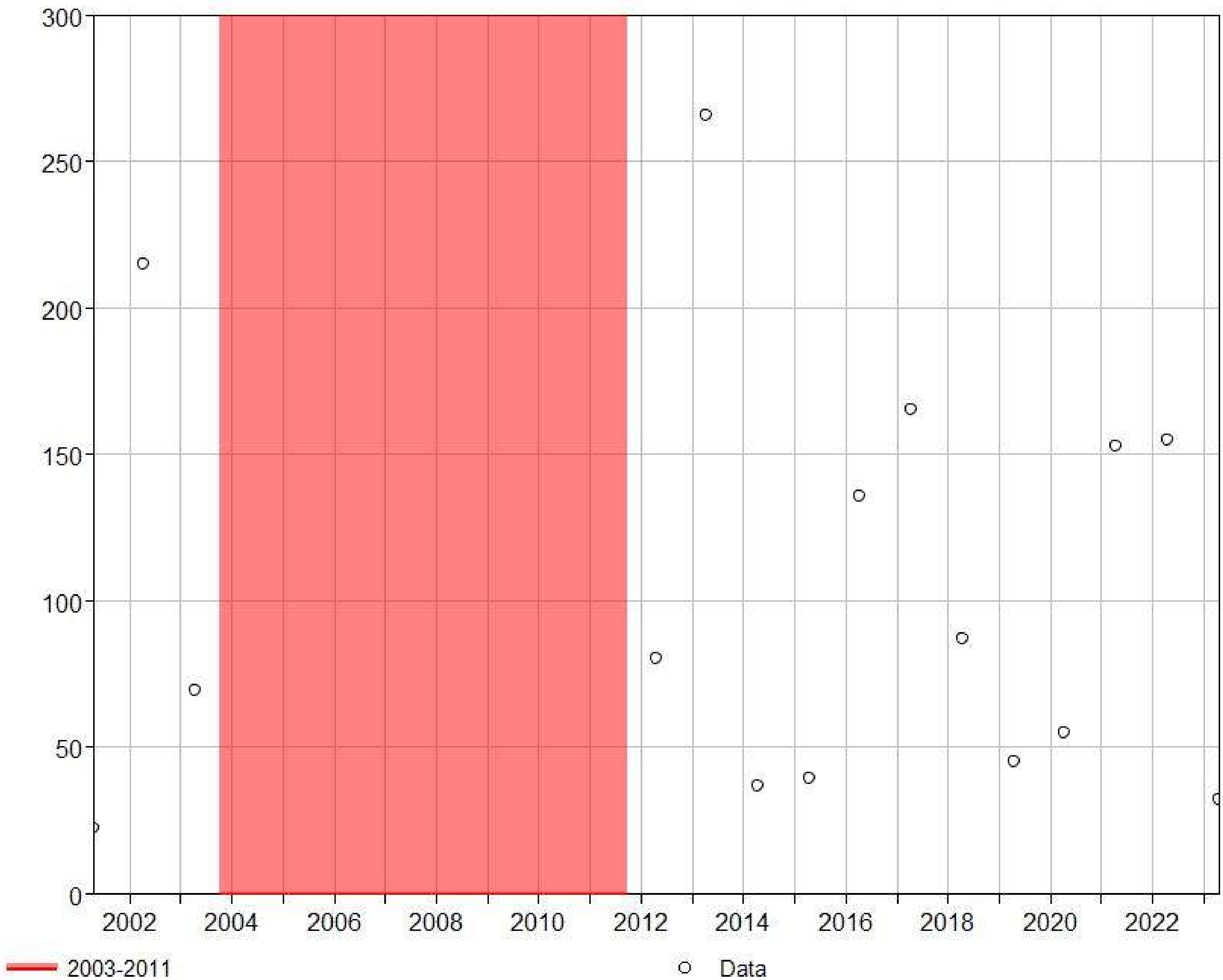
* = p-value corresponds to a zero flow value.

<< Systematic Statistics >>

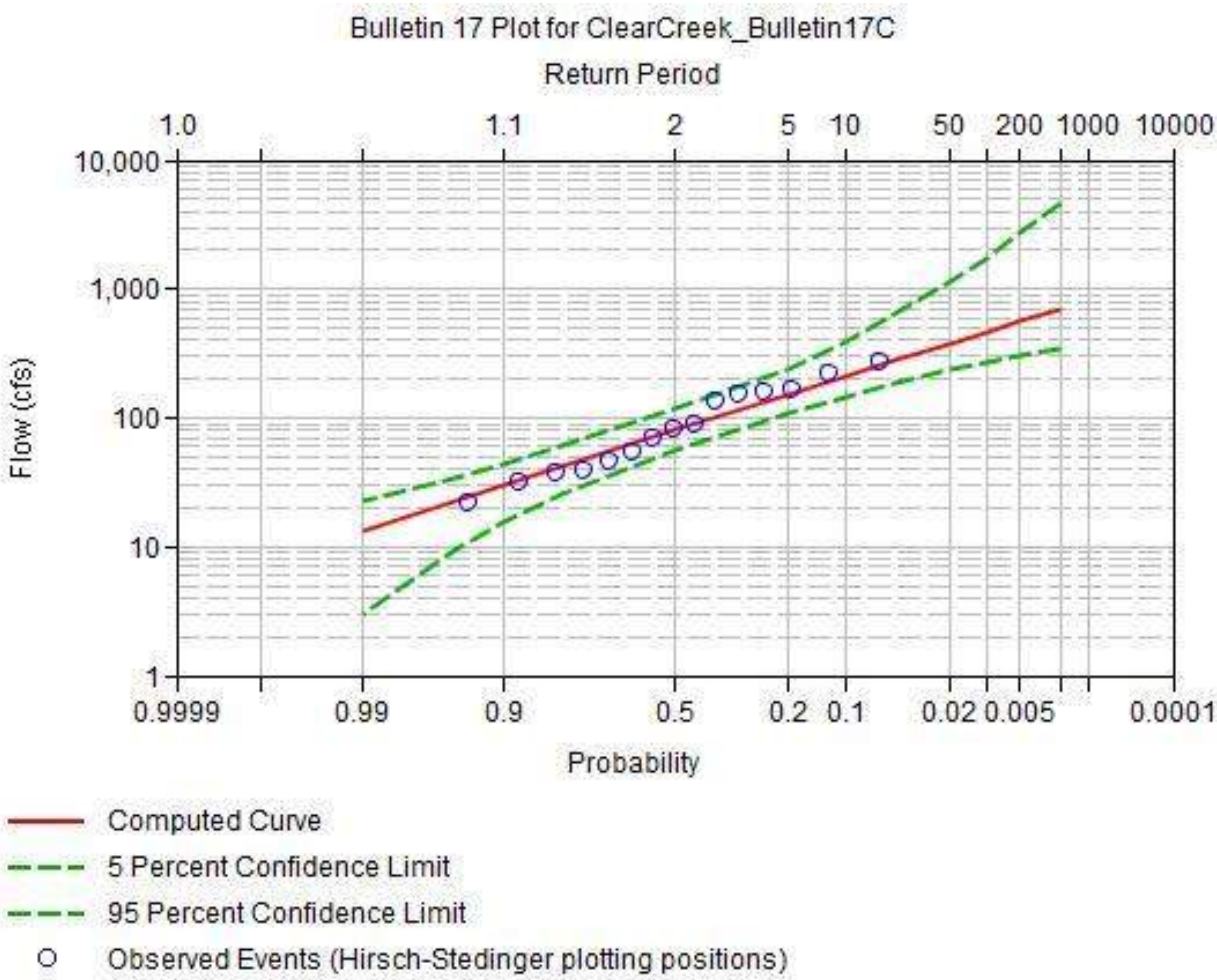
CLEARCREEK-MAX-FLOW

Log Transform: FLOW, CFS		Number of Events	
Mean	1.903	Historic Events	0
Standard Dev	0.333	High Outliers	0
Station Skew	-0.049	Low Outliers	0
Regional Skew	-0.070	Zero Events	0
Weighted Skew	-0.070	Missing Events	8
Adopted Skew	-0.070	Systematic Events	15
		Historic Period	23

--- End of Analytical Frequency Curve ---



Clear Creek-West Tributary Gage Analysis



Clear Creek-West Tributary Gage Analysis